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Learning from Fukushima

Efforts to explain what went wrong in Japan's nuclear disaster are doomed to fail if they seek to separate the social from the technological. Recognizing that all aspects of sociotechnical systems are intertwined is essential to developing wiser technology policies.

Disasters prompt us to seek lessons. After the tragic trifecta of earthquake, tsunami, and nuclear failure at the Fukushima Daiichi reactors in March 2011, many people have turned to Japan to understand what went wrong and how to prevent such an event from recurring. As we approach the first anniversary of the earthquake, there still seems to be little agreement on what these lessons should be. Some point to the relatively minor release of radioactive material and the outdated design of the reactors to argue that nuclear power is safe, whereas others take Fukushima as blatant evidence that nuclear power remains unsafe. Germany responded to Fukushima by accelerating its nuclear exit, but France reaffirmed its strong commitment to nuclear energy. Moreover, as with previous nuclear accidents at Three Mile Island and Chernobyl, lessons tend to fall within one of two categories: those that blame technology, such as the reactor design, and those that blame social factors, such as poorly conceived regulations or corporate greed.

We argue that it is impossible to separate the social and technical features in a complex operation such as Fukushima. Nuclear power is best understood as a thoroughly hybrid entity in which the social and technological cannot be separated from one another for analytical or policy purposes. Technologies such as reactors, risk models, and safety mechanisms are embedded in social values and practices; similarly, national identity, risk regulation, and corporate culture are materialized in the production and operation of nuclear power plants. Acknowledging these irreducible linkages, we critique several analyses that apply a strictly technical or social lens to Fukushima and illustrate how a sociotechnical approach results in a more realistic and useful understanding of events. This more complex account uncovers a different set of lessons and points to novel responses that include participatory technology policy, global nuclear governance, and a more reflexive approach to modeling.

It's not just politics

One common refrain has been that Fukushima happened because politics interfered with technology, leading to political biases in risk assessments and safety reports as well as inconsistent regulation by industry-captured government authorities. According to this narrative, political influence should be prevented by shifting power to regulators and expert scientists, who are assumed to be objective and independent. Politics should be excluded.

In contrast to this storyline, we argue that the failure at Fukushima was not just that decisions were political, but that they were asymmetrically and incompletely political. A technological system should not be seen as political only when things go wrong. Rather, political values and interests are continually part of nuclear operation, including periods of normal management and robust technological performance. From a sociotechnical perspective, the challenge is not to exclude politics but to ensure that political agendas and channels are transparent, explicit, and open to debate.

As in all other nations, nuclear power in Japan has always been deeply political. In the aftermath of the nation's disastrous defeat in World War II, several Japanese politicians were looking for ways to build the country's legitimacy and demonstrate its technological capacity. For the later prime minister and nationalist Yasuhiro Nakasone and for media mogul Matsutarō Shōriki, who in 1956 became the first head of the Japan Atomic Energy Commission, nuclear power was a vehicle for national prestige and honor. To involve its citizens in its nuclear agenda, the Japanese government

The Fukushima meltdown was not an isolated and accidental case of a technology being corrupted by a few politically motivated individuals. Instead, the entire Japanese nuclear power industry was a designated October 26 as a Day of Nuclear Power to commemorate the first successful operation of an experimental reactor at Tokai in 1963, exactly seven years after Japan joined the International Atomic Energy Agency (IAEA). The state offered incentives to communities willing to host nuclear power plants, undertook publicity campaigns to promote atomic energy, and mandated the inclusion of “safe nuclear power” visions in schoolbooks. Moreover, the government’s modernization efforts were enthusiastically supported by wartime industry conglomerates Mitsui, Mitsubishi, and Sumitomo, which continued to be cornerstones of national identity.

product of a highly cultivated, decades-long political agenda of crafting a strong Japanese national identity.

In short, nuclear power has never been a value-neutral technology, in Japan or elsewhere. The creation of the Japanese nuclear power industry was directly tied to the political goal of reestablishing Japan as a strong and powerful nation. However, nation-building around the atom represented only one of the possible political positions. Although the interests of the central state, modern science, and several large corporations were articulated clearly, democratic deliberation about the management and distribution of risks from this national project received much less attention than did narratives of modernization and growth. Japanese antinuclear activists such as the nuclear chemist Jinzaburō Takagi have noted that the dissenting views have been consistently discouraged by the state. For example, when the Japanese government responded to citizen protest in 1977 by allowing meetings on proposed nuclear power plants, the resulting hearings were highly scripted affairs where questions were screened in advance and speakers were cut off by the moderators. In the minds of state technocrats, being a good Japanese citizen meant supporting these state efforts, thus helping the nation rise up from shame and defeat to become an economic superpower. In this sense, the Fukushima meltdown was not an isolated and accidental case of a technology being corrupted by a few politically motivated individuals. Instead, the entire Japanese nuclear power industry was a product of a highly cultivated, decades-long political agenda of crafting a strong Japanese national identity.

The way forward, then, does not lead to less politics but to more political deliberation. Nuclear power for a developed nation in the 21st century cannot be sustained on the same moral and strategic grounds as in a post–World War II setting. Thus, developing alternative technology policy options, in Japan and elsewhere, means reassessing old narratives of national resurrection and economic growth at all costs that once served as the justification for nuclear power, as well as the inherited technocratic structures that came with it. Moreover, it means allowing publics to participate in building a new vision of technological progress that takes a wider range of values into account, facilitated by a more robust and open set of political mechanisms that allow dissent and local citizen autonomy as part of technological advancement and national self-imagination. Although state experts may have greater scientific knowledge than does the average citizen about how nuclear power plants should be designed and operated, this does not justify unquestioned authority over all decisions. In particular, it does not substitute for citizen input as to why a society should pursue a hazardous industry such as nuclear power, where and under which risk assumptions plants should be located, and what types of safety measures should be used. Consultative exercises, employing citizen juries and social media for example, as well as state responses to citizen protests, can lead to improved safety and greater attention to the equal allocation of costs and benefits. More open and comprehensive politics make for better technology.

It’s not just Japan

Another storyline explains Fukushima in terms of failures specific to Japan: Japanese geography is unlike any other; Japanese regulators were too close to company officials to notice flaws in risk assessment or mandate additional safety features in the design basis for reactors; Tokyo Electric Power Company (TEPCO) responded to the disaster in a slow and bumbling manner; the Japanese media were prevented from raising critical perspectives by the state and by a public culture of deference to authority. The responsibility for the disaster, in this view, lies within Japan’s borders, and the problem can be solved by improving the accountability of the Japanese state and nuclear industry.

We argue that both the origins and consequences of Fukushima are thoroughly transnational and should be addressed through an enhanced regime of global nuclear governance. The focus on Japanese exceptionalism masks the extent to which sociotechnical systems such as nuclear power are enmeshed in global networks of exchange and prestige.

Japan’s nuclear history began in global conflict. During World War II, Japan sought to develop a nuclear bomb, and it was the dropping of atomic weapons at Hiroshima and Nagasaki in 1945 that brought the realities of splitting the atom into public view. Eight years later, U.S. President Eisenhower delivered his “Atoms for Peace” speech at the United Nations, in which he offered U.S. assistance to other nations interested in developing nuclear power. Drawing on his U.S. political connections, Japan’s Harvard-trained prime minister–to–be Yasuhiro Nakasone gathered support for a nuclear technology budget in Japan’s House of Representatives three months later. Over the next several decades, a generation of Japanese scientists trained abroad at institutions such as the U.S. Argonne National Laboratory, and the nation’s first reactors were purchased from foreign companies such as GEC (United Kingdom), Westinghouse and GE (United States), and Areva (France). Nuclear fuel was obtained from uranium mines in Australia, Canada, and elsewhere. As Japan became the world’s third largest producer of nuclear energy, the electricity from these plants went into producing manufactured goods that were consumed around the world and drove Japan’s rise as an economic superpower. Japanese companies benefited greatly from technological spillovers from nuclear engineering.

Fukushima’s aftermath provides more evidence that Japan’s nuclear decisions reach beyond national borders. Radioactive materials were carried across the globe, being detected as far away as the United Kingdom. Sony, Toyota, and numerous other multinational Japanese companies fear that a nuclear stigma will attach to the “made in Japan” brand, adding to the record losses from the earthquake and tsunami, and in turn altering business expectations for foreign competitors and dependent manufacturers. Germany’s energy industry, faced with a new wave of antinuclear resentment, is threatening that the plan to close all reactors in Germany will result in bankruptcy and blackouts. This reveals how, tacitly or otherwise, the costs and benefits of nuclear power cannot be contained within a single country.

Fukushima’s global origins and repercussions suggest that current national models of nuclear governance are not adequate. In light of the extensive supranational linkages, it seems anachronistic at best that key regulatory aspects of power plant licensing and security and safety standard-setting should remain the exclusive preserve of national governments. The time has come to separate national economic and political interests in promoting nuclear power from the regulatory function, which concerns all nations. History suggests that significant changes in nuclear governance are both possible and desirable. For example, in 1974 the U.S. Atomic Energy Commission was split into the

Nuclear Regulatory Commission and the Energy Research and Development Administration, with standard-setting delegated in part to the Environmental Protection Agency. This separation reflected the insight that the promotion and regulation of nuclear energy do not sit comfortably within the same body. Likewise, the Japanese government is now considering separating the Nuclear and Industrial Safety Agency from the Ministry of Economy, Trade and Industry, which promotes the use of nuclear energy.

In a similar vein, we recommend elevating the mandate of the IAEA to include a licensing function for nuclear power plants, thereby changing its status from an advisory body to that of an international institution with authority to make legally binding decisions. Such a move would go beyond other suggested expansions of the IAEA mission in light of Fukushima, such as the inclusion of response mechanisms to disasters. Under this new international regulatory regime, a global community would be involved in decisions about the siting of nuclear power plants, the proliferation of reactor technology, safety enforcement, and financial responsibility for events such as Fukushima. Nuclear disasters do not respect national borders, and governance models must therefore include a significant global dimension.

It’s not just the models

Inadequate risk assessment models have been identified as another main culprit in the Fukushima disaster. TEPCO’s models were criticized for having recommended the construction of a 5.7-meter retaining wall “based on tsunami folklore,” which was overwhelmed by a 14-meter tsunami wave crest. Moreover, TEPCO’s reactors suffered leakages from the 9.0 earthquake that would have been perilous even without the “unexpected” tsunami taking down the supposedly fail-safe emergency cooling systems. Had the models been correct and correctly followed, the story goes, the disaster might have been averted through the incorporation of more robust defenses into the original reactor design.

We argue that nuclear safety is not simply a matter of developing more powerful models and more accurate worst-case scenarios. It is equally about developing better strategies for societies to understand the role of modeling and deal with the inescapable limitations of all models. The modeling of complex sociotechnical systems itself incorporates sociotechnical assumptions that modelers and decisionmakers need to keep in mind.

Contrary to our common-sense understanding of modeling, models of sociotechnical systems frequently evade the empirical validation that is a touchstone for engineering quality. To test for a cumulative probability of a one in ten million chance of a nuclear failure each year would require building 1,000 reactors and operating them for 10,000 years, as noted by Alvin Weinberg in his famous 1972 article “Science and Trans-science.” In actuality, the number of data points that are relevant to our models of systems safety for nuclear power is relatively small. The most prominent ones—Three Mile Island, Chernobyl, and Fukushima—arose from very different circumstances, invalidated different modeling and risk assessment assumptions, and resist being assimilated into a single data set. The events are too idiosyncratic to allow easy generalizations about where our models fail, though they seem to suggest that annual failure-risk estimates such as one in ten million or even one in ten thousand are a serious underestimation.

Despite tremendous progress in systems thinking, modeling, and computation power, we are not yet able to synthesize insights from domains as diverse as geophysics, nuclear engineering, hazard containment, atmospheric physics, and hydrology, let alone individual and social psychology, history, and politics into a single conceptual framework . Nor is it realistic to expect that these challenges will ever be completely overcome. No improvement will ever exclude the possibility of unpredictable emergent behavior, which is a characteristic of complex systems. Fukushima underlines yet again that there are no good models without robust societal mechanisms to deal with their inescapable uncertainties, limitations, and failures.

Modeling complex sociotechnical processes thus remains in part a scientific exploration of the adequacy of different modeling approaches, not simply a straightforward application of consolidated routines. Modeling a nuclear power system is not like predicting the performance of a car engine; it is closer to creating a climate change model. In the absence of comprehensive empirical tests, modelers rely extensively on extrapolation and coherence assumptions. Those who create the models are often very aware of the uncertainties. However, political and long-term investment pressures frequently drive decisionmakers who rely on models to ignore residual uncertainties and intermodel

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incompatibilities, and to operate models as if they were highly reliable and consistent. In fact, the debate and contestation inherent in both the scientific and political process often come to a halt once a model and its output are accepted as adequate. Questions such as what should be incorporated in the model and what should not, what are realistic boundary conditions, who has the authority to interpret results, and what to do with incompatible interfaces and remaining blind spots do not receive continuous attention over the lifetime of the modeled system. Only when a disaster occurs do they resurface.

uncertainties, limitations, and failures.

Acknowledging these limitations alters how we should design and operate high-impact sociotechnical systems such as nuclear reactors. We should devote more attention and resources to the likelihood that our models are imperfect, and hence to the design of robust mechanisms to respond to subsequent problems, even if our models suggest that the chance of an accident is low. Thinking about models as needing a penumbra of responses for model failure shifts the focus away from technological optimism toward practices of humility, recognizing that models provide useful, but incomplete, guidance. This implies, in particular, that modeling must be informed by an understanding of the sociocultural pathways by which the model will be applied and anticipate undesirable social outcomes. For example, we can prepare mechanisms to protect the poorest members of society, who are often the most vulnerable to accidents and disasters. At the same time, we should make the modeling assumptions and parameters that guide decisionmaking in nuclear power safety explicit, public, and open to debate, rather than black-boxing them inside inaccessible computer programs or secluded expert discussions. This can be achieved by, for example, using open processes in the planning stage of power plants that allow the public to comment on and influence the terms and consequences of models, or by including forms of international peer review for national modeling assumptions. When sensitive security information is at stake, less open mechanisms such as panel-based review could be employed. This would facilitate a self-critical process that includes healthy and robust discussion of models and is aimed at learning over time.

Lessons for sustainability

The inseparability of the social and the technical in modern technological projects prompts us to derive from the Fukushima disaster three lessons that cut against the grain of conventional thought. We conclude, first, that disasters are not caused by politics interfering with technology but are exacerbated by a spurious assumption that politics can be removed from technological design and the subsequent practices of technology policy. Room should be made for robust discussion of the politics of standard operation alongside the politics of breakdowns and disasters, including the questioning of outdated national narratives of justification. Second, the risks, benefits, and responsibilities of nuclear power have global as well as national ramifications. There is thus an urgent need for international regulatory oversight that separates nationalist goals for advanced technologies from the safe operation and maintenance of such technologies. Third, complex sociotechnical systems elude available methods of modeling and prediction, thus calling for greater humility in the reliance on models and more attention to the consequences of model failure.

Our three lessons have important implications for how to think about the sustainability of nuclear power. If we want to take Fukushima seriously as a data point—and its graveness makes it apparent that we should—then we should take it as an important case study for what it means to be sustainable in the sociotechnical environments of the 21st century. Our accent in this paper has been on the “socio” component of sociotechnical. Northern Japan is far less sustainable today than it was before the nation undertook the nuclear power project. This is a consequence of social choices that could have been made in other ways. Consequently, if nuclear power is to remain an important part of our planet’s energy mix for the 21st century, we emphasize that ensuring its sustainability requires a resolute and explicit understanding of the interconnections between society and technology. Only by taking such considerations into account can we derive lessons from the past that can generate in the future more robust democratic debates and more dependable technological systems.

Recommended reading

Daniel Aldrich, *Site Fights: Divisive Facilities and Civil Society in Japan and the West* (Ithaca, New York: Cornell University Press, 2008).

Mark Brown, “Survey Article: Citizen Panels and the Concept of Representation,” *The Journal of Political Philosophy* 14, no. 2 (2006): 203–225.

Sheila Jasanoff, “Technologies of Humility,” *Nature* 450 (2007): 33. Sheila Jasanoff, ed., *States of Knowledge: The Co-production of Science and Social Order* (New York: Routledge, 2004).

Sheila Jasanoff and Sang-Hyun Kim, “Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea,” *Minerva* 47, no. 2 (2009): 119–146.

Andrew Lakoff, ed., *Disaster and the Politics of Intervention* (New York: Columbia University Press, 2010).

Shigeru Nakayama and Hitoshi Yoshioka, eds., *A Social History of Science and Technology in Contemporary Japan: Road to Self-Reliance, 1952–1959* (Melbourne, Australia: Trans Pacific Press, 2005).

Charles Perrow, *Normal Accidents: Living with High-Risk Technologies* (Princeton, NJ: Princeton University Press, 1999).

Langdon Winner, *The Whale and the Reactor: A Search for Limits in an Age of High Technology* (Chicago: University of Chicago Press, 1989).

Brian Wynne, “The Institutional Context of Science, Models, and Policy: The IIASA Energy Study,” *Policy Sciences* 17, no. 3 (1984): 277–320.

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