Hidden Vulnerability in Fukushima Nuclear Disaster: A Sociotechnical Perspective

Sulfikar Amir, Nanyang Technological University

Dr. Shi-Lin Loh, Dr. Sulfikar Amir, and Dr. Arifumi Hasegawa at Unit 1 Reactor Building, Fukushima Daiichi nuclear power station. 12 May 2018. Photo courtesy Dr. Arifumi Hasegawa.

How could the nuclear disaster occur in a technologically advanced society where safety culture and collective discipline are of paramount importance? Is it simply due to natural forces, thus making the catastrophe inevitable? Is it primarily caused by human error? Or the failure of safety system that seemed to be impregnable?

This short paper is about these questions. It aims to investigate the fundamental problem leading to the nuclear meltdown at Fukushima Daiichi, and sets to explain why this particular problem emerged. Lying only a few hundred meters inland from the coastline of the Pacific, Fukushima Daiichi was the second largest nuclear power plant in Japan after Kashiwazaki Kariwa; both are owned and operated by TEPCO. Occupying 3.5 square kilometers just 5 kilometers from Futaba station, the huge nuclear power station complex had six reactors, the sizes of which

> ***Fukushima Daiichi was the heart of Tokyo. It was the source of energy that kept that kept a city of over twenty million citizens alive.***

ranged from 430 to 1100 MW. They were all boiling water reactors (BWR) in Mark I containment, except Unit 6 which had Mark II. The first reactor began construction in 1966 and was first commissioned in March 1971, while Unit 6 began to produce electricity in October 1979. At full capacity Fukushima Daiichi could generate 4.6 gigawatt of electricity. All electricity produced from this plant was delivered to Tokyo to light up millions of glaring neon signs and streetlights across the megacity especially in the most vibrant areas such as Shibuya, Shinjuku, Ginza, and Ueno. In other words, Fukushima Daiichi was the heart of Tokyo. It was the source of energy that kept that kept a city of over twenty million citizens alive. And for four decades it contributed to providing tremendous amounts of energy for the continued growth and prosperity of Japan especially during the economic miracle.

The size and scale of Fukushima Daiichi was not the only feature of which TEPCO was deeply proud regarding this nuclear facility. The utility company was equally proud of the safety system with which Fukushima Daiichi was equipped. It was claimed to be the most cutting-edge in its era, and its so-called defense in depth was considered the strongest to protect the facility from various external threats. It consisted of multiple independent and redundant layers of defense, ranging from the use of access controls, physical barriers, diverse key safety functions, to emergency response measures. This integrated safety system presumably gave the operator the ability to ward off fatal accidents due to both human and mechanical failures. As the promotional video of Fukushima Daiichi explicitly stated, "*More than enough* attention to safety is applied." [emphasis added] Unfortunately, what transpired in the 3.11 events proved this claim ungrounded.

Fukushima Daiichi was not the only nuclear facility terribly slammed by the 2011 tsunami. Another three nuclear power plants also suffered from the tsunami. One of them is Onagawa[1] in Miyagi Prefecture whose location is much closer to the earthquake epicenter. Only Fukushima Daiichi eventually plunged into a prolonged crisis. So what's wrong with Fukushima Daiichi? A crucial factor is foregrounded, one that serves as the entry point of this paper in describing the unfolding of the nuclear disaster. Like all Japanese nuclear power plants, each of Fukushima Daiichi reactors was connected to the seismic instrumentation system designed to cease the reactor operation when a significant impact from earthquake hit the reactor. It is a safety system known as SCRAM. When the magnitude 9 earthquake erupted and devastated the Tōhoku area, Unit 1, 2, and 3 were operating. The remaining units were under maintenance for a periodic inspection. In the wake of the earthquake, the typical emergency response of nuclear power stations consists of three sequential steps: shutdown, cooling, and containment. Fukushima Daiichi went through the first step successfully when peak ground accelerations caused by the underwater megathrust reached the plant. All the operating reactors were scrammed at once after a signal was received from the seismometer. Following this came the measures to cool the reactors. This was a critical part, as the reactor pressure vessel still contained decay heat generated from previous fission processes. Decay heat removal relied on the cooling system that ran on electricity. Fukushima Daiichi lost the off-site power supply because the earthquake crashed most of the transmission lines in the area. The station then switched to a back-up electrical power. It came from several emergency diesel generators (EDGs) attached to each unit of the reactors. The cooling process operated as designed without disruption, but only until an undesigned 13-meter high tsunami, higher than the defense seawall, arrived less than an hour later. In the blink of an eye, tsunami water massively flooded the plant. This should have not caused much problem if it had not been for one factor; all the EDGs were located in the basement. Seawater rapidly inundated the basement and ruined all the electrical instruments in it, including EDGs and the switch control. The consequence of these instruments being damaged was catastrophic. Fukushima Daiichi went SBO, a term in nuclear emergency system standing for "station black out". This is a situation where the entire plant completely loses power supply. It is a nightmare that every nuclear power operator fears the most. In Fukushima Daiichi, it led to the failure to stabilize the reactors, resulting in a series of meltdowns.

In retrospect, many factors contributed to the nuclear meltdown in Fukushima Daiichi. They range from the insufficient height of seawall, to the lack of waterproofing of the EDG room, to the sloppy response of the nuclear emergency team in Tokyo. Yet, the most fatal shortcoming is the location of EDGs in the basement, which played a pivotal role in triggering a chain reaction of fatal failures. The fact is that this technical feature was part of General

[1] See for example Airin Ryu and Najmedin Meshkati (2013) Why You Haven't Heard About Onagawa Nuclear Power Station after the Earthquake and Tsunami of March 11, 2011. Available: http://www-bcf.usc.edu/~meshkati/Onagawa%20NPS-%20Final%2003-10-13.pdf

Electric's original design of the reactor building when it was constructed in Fukushima. It was built with no modification whatsoever. And for the next four decades, no changes had been made on this particular arrangement of safety system.

This technical mishap plaguing Fukushima Daiichi epitomizes what I call hidden vulnerability. It is a vulnerability that remained hidden until the tsunami came to reveal it. It is bewildering to think why a tsunami-prone country could not think of this weakness and take necessary actions accordingly when building and operating a mega- scale nuclear power plant located on the seaboard. My experience visiting Fukushima Daiichi is never more relevant to understanding vulnerability of this nature. When Yoshizawa and his TEPCO colleagues were convincingly showing me how safe Fukushima Daiichi was, vulnerability was actually lurking underneath in the basement, which no one ever managed to recognize, let alone remedy. None of us would have ever imagined the tragic fate Fukushima Daiichi would end up two years later. Why did the vulnerability in Fukushima Daiichi remain hidden for such a long time?

…vulnerability is produced in the intersection of the technical and the social whereby the design and everyday practices of safety culture are conditioned by the assemblage of social forces within and without the system. This means vulnerability is deeply embedded in the sociotechnical formation of infrastructures.

Hidden vulnerability is both a phenomenon and a concept. It is a phenomenon because it materially exists in a technical configuration whose potential to erupt is unrecognized. Concurrently, it is an analytical concept used to explain the fundamental problem of how technologically advanced societies with incredible cultures of discipline can fall into technological disasters of this magnitude. While being materialized in technical structures, vulnerability is inextricably intertwined with organizational patterns and institutional structures. In this paper I argue that vulnerability is produced in the intersection of the technical and the social whereby the design and everyday practices of safety culture are conditioned by the assemblage of social forces within and without the system. This means vulnerability is deeply embedded in the sociotechnical formation of infrastructures. From this vantage point, we need to explore the complex inter-relations of institutions, politics, and technical arrangements that kept the vulnerability of Fukushima Daiichi hidden until the tsunami came to shock the purportedly unbreakable protection and reveal its vulnerabilities.

To pursue this goal, it is necessary to clarify what it is meant by "hidden vulnerability". A vulnerability is hidden when the entire sociotechnical entity is fully pre-occupied by a widely shared conviction that all necessary measures have been fulfilled to recognize potential failures, mistakes, and malfunctions that could lead to serious accident. It is hidden because this kind of vulnerability escapes attention of the system's precautionary principles, and remains invisibly embedded in safety system procedures, and operational practices. It is hidden because regulatory bodies and operating organizations fail to recognize, or misrecognized, the presence of this vulnerability and its potential to wreak havoc on the standing structure and to paralyze system stability, durability, and robustness. It is hidden because the dominant epistemology of safety culture undermines vulnerability as a benign manageable risk, or even decides to ignore altogether its catastrophic potential. That being said, hidden vulnerability is a relative term. Vulnerability may be hidden to some, while being visible to others. What constitutes "hiddenness" lies in the presence or absence of realization of actions by responsible actors to remedy the vulnerability in such an organized fashion. Vulnerability will continue to go hidden should realized actions never occur or be deemed unnecessary.

A question ensues from this conceptualization: What renders vulnerability to be hidden? We can refer to the insights organizational sociologists have provided to illuminate the consequence of structures. Both theoretical frameworks can be synthesized under the rubric of "institutional structure," which encompasses the whole arrangement of organizational entities and the distribution of authority and roles designed to perform specific goals for the operation of a sociotechnical system. The invisibility of vulnerability is attributed to the way in which sociotechnical institutions are structured. However, this only captures one side of the story. The characterization of hidden vulnerability above suggests another contributing factor. This paper emphasizes that hidden vulnerability is not only a structural issue. It is also an epistemological one. A problem is epistemological when it raises concerns in regards with the production and utilization of knowledge. In other words, epistemology relates to things that constitute knowledge system. In a complex world of risk, knowledge system can render vulnerability unrecognized. This instrumental element is not addressed in existing accident-analysis frameworks such as normal accidents and normalization of deviance. To dwell into this aspect of hidden vulnerability, we need to explore another intellectual domain, namely Science and Technology Studies (STS) where knowledge production and expertise are problematized.

Langdon Winner, for instance, developed the making explicit of how "technology can be used in ways that enhance the power, authority, and privilege of some over others" into a subfield of investigation we can call technological politics.[2] Technological politics points to the capability of technology of facilitating power relations in which political goals are pursued through technological means, and vice versa. A deeper look into technological politics exposes certain technologies to be inherently political. Power is embodied in material configurations of technology, and concurrently technical systems are designed to be strategically aligned with political structure. At the macro level, the impact of this amalgamation results in the formation of what Gabrielle Hecht refers to as technopolitical regime, an institutional structure that arises to facilitate the construction of high technology imbued with power and political interest.[3]

The vantage point of technological politics paves the path for a more meaningful explanation on the origins of hidden vulnerability. It allows us to examine the possibility of different arrangements of institution to structure technological systems following the logic of power and ideological interest. The implication is that our analysis of hidden vulnerabilities requires an understanding of both the epistemologies and politics of how technological risk is defined, categorized, and measured. Whether or not vulnerability becomes visible is in many ways dependent on how knowledge of risk is formulated, arranged, and institutionalized by the technopolitical regime. This is the bottom line of the epistemological cause of hidden vulnerability. Accordingly, this paper situates hidden vulnerability as a problem of knowledge hinged upon power relations. It exposes the limit of expert knowledge in recognizing the vulnerable component lurking underneath the complex infrastructure. Thus, underlying hidden vulnerability is a fundamental epistemological issue in shrouding risk realities because knowledge is produced only to eschew certain areas of risk.

Informed by the STS critical insights on knowledge and technological politics discussed above while adopting the structural analysis from Charles Perrow and Diane Vaughan, we can propose two interlocking factors as the explanation for the production of hidden vulnerability in Fukushima Daiichi.

First, a number of individuals have been brought to the court for being allegedly responsible for causing the awful fate of Fukushima Daiichi. These include middle- ranked employees, nuclear experts, and executive board members of the utility company.[4] While it is important to enforce accountability for the enormous scale and

[2] Winner, L., 2010. *The whale and the reactor: A search for limits in an age of high technology*. University of Chicago Press.

[3] Hecht, G., 1998. *The radiance of France: Nuclear power and national identity after World War II* Cambridge. MA: Massachusetts Institute of Technology.

[4] (1) "Bringing Tepco officials to trial" http://www.japantimes.co.jp/opinion/2015/08/06/editorials/bringing-tepco-officials-trial; (2) "Trio on trial over

amounts of social, economic, and environmental damages brought about by the Fukushima nuclear disaster, it does not necessarily explain why these individuals were not able to perform their duty properly in keeping safe operation of nuclear power. Individuals are "rational actors" whose behavior is strongly forced by the institutional environment. When the environment gives incentive for good behavior, individuals are likely to respond accordingly. Likewise, if the environment tolerates bad behavior, the collective action will result in highly detrimental outcome. The bottom line is that the pattern of individual interactions and power relations are shaped by the way in which the institution is structurally arranged. We can consider this as a systemic problem plaguing the nuclear industry in Japan. The industry structure has over time grown to the point where function and authority of each governing agency became blurred and overlapped one another.[5] In this convoluted structure of regulatory bodies and operating organizations, the tendency to underestimate potential risk and hazards remains strong, entailing slack implementations of safety culture. Conditioned by bureaucratic inertia, economic and political interests, and ideological myth, the chances are high for vulnerability to go unnoticed.

Second, unlike some scholars who suggest that the failure of Fukushima Daiichi in anticipating the meltdown has to do with a lack of expertise,[6] this paper argues that it is not the absence of expertise, or a lack thereof, that brought devastating impact on the facility. For several decades, Japan had successfully developed a body of scientific knowledge aimed at measuring and mitigating disaster of various types. In fact, given the proclivity toward natural disasters, most notably earthquake and tsunami, Japanese expertise in disaster mitigation is considered one of the best in the world.[7] This applies to the area of nuclear safety and emergency. The Japanese nuclear industry is one of the most advanced in terms of reactor design and technology, which encompasses nuclear safety and radiation protection. Thus, it is inaccurate to describe the Fukushima nuclear disaster as resulting from a condition of poor expert knowledge. In contrast, this paper underscores a produced epistemological bias within the assembly of risk and vulnerability protocols as the main reason for the Fukushima Daiichi disaster and blindness to what in retrospect seems an elementary vulnerability. Epistemological bias[8] means knowledge and expertise are focused only on areas acknowledged and allowed by the institutional environment, preventing out of the box thinking, or simply stress testing assumptions about risk and vulnerability. This as such creates blindspots that hinder experts from recognizing sidelined domains where embryonic vulnerabilities are emerging. Epistemological bias is deeply embedded in practices of risk analysis and safety engineering, and it is reinforced by unfettered confidence in robustness and reliability of nuclear power system. It draws the use of scientific knowledge on certain domains of risk, which are narrowly defined and biasedly informed by interests in knowledge production that feed on the nuclear industry.

This elucidates hidden vulnerability as born out of a mixed assembly between the epistemological bias and convoluted structure that fosters a chronic complacency within the system. The problem of recognizing hidden vulnerabilities, however, is more than simply one of noticing. There is an active propagation of ignorance, which can be viewed as an emergent feature precipitated by a synergy between the two features noted above. The literature on ignorance studies is steadily expanding of late, particularly around risk and vulnerability.[9] These

Fukushima nuclear disaster" http://www.euronews.com/2017/06/30/trial-of-tepco-executives-responsible-for-fukushima-begins; (3) Former TEPCO bosses indicted over Fukushima meltdown http://www.cnn.com/2016/02/29/asia/tepco-bosses-indicted-fukushima/index.html

[5] This comes close to what Miwao Matsumoto characterizes the nuclear disaster in Japan as "structural disaster", which is a result of the institutional predicament marked by secrecy and a lack transparency. See Matsumoto, M., 2013. "Structural Disaster" Long Before Fukushima: A Hidden Accident. Development and Society, 42(2), pp.165-190.

[6] See for example Nakamura, A. and Kikuchi, M., 2011. What we know, and what we have not yet learned: Triple disasters and the Fukushima nuclear fiasco in Japan. *Public Administration Review*, 71(6), pp.893-899.

[7] For a comprehensive description of Japan's disaster management especially in relation to the 3.11 disaster, see Suzuki, I. and Kaneko, Y., 2013. *Japan's disaster governance: how was the 3.11 crisis managed?* Springer Science & Business Media.

[8] This notion was first applied in Amir, S. and Juraku, K., 2014. Undermining disaster: engineering and epistemological bias in the Fukushima nuclear crisis. *Engineering Studies, 6*(3), pp.210-226.

[9] Some notable works in ignorance are, among others, Gross, M., 2010. *Ignorance and surprise: Science, society, and ecological design*. MIT Press; Frickel, S. and Vincent, M.B., 2007. Hurricane Katrina, contamination, and the unintended organization of ignorance. *Technology in Society, 29*(2), pp.181-188; Peels, R. and Blaauw, M. eds., 2016. *The Epistemic Dimensions of Ignorance.* Cambridge University Press.

important works bring attention to "the instrumental value of ignorance and examine its relationship with other forms of partial or limited knowledge."[10] In light of these lines of inquiry, the paper is particularly concerned with institutionalized ignorance, which is becoming recognized as an acute, rather than just passive or potential problem in high-risk sociotechnical infrastructures. Ignorance is institutionalized when a set of legal instruments such as laws, decrees, and regulations are conceived based on narrow assessments of risk, narrowed to legitimize the undertaking of large-scaled projects fully loaded with promises to deliver prosperity and technological supremacy.[11] Unfettered desire towards economic growth and competitiveness nurture certain patterns of ignorant behavior that in long terms compromise safety culture and precautionary principles. As this paper shows, institutionalized ignorance has considerable consequences on the silent construction of hidden vulnerability.

Discussion Comments
by **Darren Byler**, incoming Assistant Professor of International Studies at Simon Fraser University in Vancouver, British Columbia

Technological Disempowerment

It was a great pleasure to read Sulfikar Amir's excellent paper on hidden vulnerability. Like all good scholarship, his work opens up new domains for thinking—something that I'll voice through a few open questions in this short response. The paper also evokes the phenomena under examination. It starts by painting a vivid picture of the power plant before the disaster—letting the reader share in the immensity of space, the awe of radiant blues at the nuclear core, the blast of exuberant music that played in the airlock. Thinking with the network of the power grid Amir provides an image of the Tepco plant as the beating heart of Tokyo—since the energy it produces is what powers significant portions of the city. Here there is a framing of a kind of off-shoring of risk—farming out the hazards of energy production to a space that is devalued relative to the metropole. Amir notes that this kind of exposure is an alternative reading of vulnerability, or perhaps precariousness—and here I'm thinking in particular of Anne Allison's work (2014)—in the differential deployment of power over life.

But the center of the paper is pointed not toward differential experiences of exposure, or assigning blame, as much as systemic fragility. Amir elucidates a number of key concepts and phenomena central to understanding the political life of complex infrastructural systems. He shows that epistemological bias and institutional ignorance are key to understanding hidden gaps in knowledge and practice. This system vulnerability comes from a combination of bureaucratic inertia, ideological myth and political interests. It happens when risk assessments are narrowed to legitimize projects that state authorities and capital deem priorities. Importantly though he also notes that "power is embodied in material configurations of technology" "and technologies are aligned with political structure." Hidden vulnerability he suggests comes from not being able to ask certain questions. There is an "active propagation of ignorance" precipitated by bias and institutional structures.

This provocative claim pushes me to think about what kinds of questions are rendered out of bounds. The first domain it makes me consider is at the political level; the level of state power and national economy. Is the former kind of vulnerability—the differential exposure of devalued life—one of the questions that cannot be fully asked? How was the risk of positioning a nuclear power plant in a tsunami red zone calculated? Why was the plant not positioned in Tokyo if that is where the power was needed? If it had been built in Tokyo, would the emergency generators been placed in an unwaterproofed basement? Would the sea wall have been higher? Or is the more fundamental unasked question why nuclear energy at all?

---

[10] See Gross, M. and McGoey, L. eds., 2015. *Routledge international handbook of ignorance studies.* Routledge.
[11] I first used this notion in my article Amir, S., 2014. Risk State. *Routledge Handbook of Science, Technology, and Society*, p.292.

I'm also interested in Amir's description of power as "embodied in material configurations of technology" as perhaps a second domain of thinking with materiality. This framing of power as embodied in the material makes me wonder how exactly power is related to the technologies, and as the technologies evolved how those relationships have evolved? Writing about a radically different context of state power in Northern Ireland in the 1980s, Allen Feldman has argued that power is not in fact "distributed" from a center of power held in reserve as much it is actualized through a "metonym of doing." The state ultimately is a powerful fiction given form and effect through institutional and material processes. And the material systems and institutions of a state are set up in such a way to prevent thinking and action outside of particular specialized domains. I've found in my own research on advanced surveillance infrastructures in China that infrastructure power distributes the doing of power into discrete spaces and specific tasks. Often it is just scans of codes or scans of faces which have been reduced to code. The digitization and automation of platform technologies often render technicians ignorant of how the system works as a whole and its ultimate effects. All this makes me wonder about the role of complex technology and power within nuclear power systems. Could hidden vulnerability be framed as a result of a kind of materially generated disempowerment? How does the increased automation and specialization of technical tasks shape power relations and the ability to ask questions about the fragility of such systems?

Works Cited:
Allison, Anne. Precarious Japan. Duke University Press, 2014.
Feldman, Allen. Formations of violence. University of Chicago Press, 1991.

Sulfikar Amir *is an Associate Professor of Science, Technology, and Society (STS) and a faculty member in Sociology Programme at the School of Social Sciences, Nanyang Technological University in Singapore. His research interests primarily focus on examining institutional, political, and epistemological dimensions of scientific knowledge and technological systems. He has conducted research on technological nationalism, development and globalisation, nuclear politics, risk and disaster, design studies, city and infrastructure, and resilience. Sulfikar Amir is the author of "The Technological State in Indonesia: the Co-constitution of High Technology and Authoritarian Politics" (Routledge, 2012), and the editor of "The Sociotechnical Constitution of Resilience: A New Perspective on Governing Risk and Disaster" (Palgrave, 2018).*

Anthropologist ***Darren Byler*** *is an incoming Assistant Professor of International Studies at Simon Fraser University in Vancouver, British Columbia and a post-doctoral research fellow in the China Made Project at the Center for Asian Studies, University of Colorado Boulder. He is the author of a forthcoming ethnography titled Terror Capitalism: Uyghur Dispossession and Masculinity in a Chinese City and a narrative-driven book titled In the Camps: China's High-Tech Penal Colony. His current research interests are focused on infrastructure development and global China in the context of Xinjiang and Malaysia.*