Managing the Fukushima Challenge

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The Fukushima Daiichi accident raises a fundamental question: Can science and technology prevent the inevitability of serious accidents, especially those with low probabilities and high consequences? This question reminds us of a longstanding challenge with the trans-sciences, originally addressed by Alvin Weinberg well before the Three Mile Island and Chernobyl accidents. This article, revisiting Weinberg’s issue, aims at gaining insights from the accident with a special emphasis on the sociotechnical or human behavioral aspects lying behind the accident’s causes. In particular, an innovative method for managing the challenge is explored referring to behavioral science approaches to a decision-making process on risk management; such as managing human behavioral risks with information asymmetry, seeking a rational consensus with communicative action, and pursuing procedural rationality through interactions with the outer environment. In short, this article describes the emerging need for Japan to transform its national safety management institutions so that these might be based on interactive communication with parties inside and outside Japan.

KEY WORDS: Fukushima Daiichi accident; risk communication; trans-sciences

1. INTRODUCTION—LESSONS LEARNED FROM THE FUKUSHIMA DAIICHI ACCIDENT

The Fukushima Daiichi nuclear power station accident of Tokyo Electric Power Co. (TEPCO) was caused primarily by the immense tsunami following the Great East Japan Earthquake (M9.0), the largest earthquake recorded in Japan. The tsunami hit the eastern coast of northern Japan on March 11 (3.11), 2011. The resulting accident has led to an enormously lengthy process of accident cleanup directed toward achieving an ultimately safe condition for the damaged nuclear reactors, Fukushima Daiichi Units 1–4, as well as the surrounding region.

In the aftermath of the accident, a number of useful suggestions and recommendations regarding the causes and lessons have been reported, both nationally and internationally, and the safety of nuclear power plants (NPPs) has been reexamined extensively in every country. In the United States, for example, the Nuclear Regulatory Commission (USNRC) has undertaken several near-term actions that were recommended shortly after the accident by the report of a special US NRC task force. In Japan, there have been multiple investigative committee reports released so far, and the new regulatory body promulgated revised safety requirements in July 2013, taking into consideration the recommendations indicated in the many reports.

Keeping in mind the repetitive nature observed in the world history of nuclear reactor accidents, however, some further in-depth investigations are necessary, in particular, with a profound insight on sociotechnical aspects of the accident’s causes, i.e., aspects related to the interaction with society or human behaviors at many different levels: individual, organizational, and national. Those aspects were more or less illustrated in the past reactor accidents as an essential factor giving rise to the accidents, and yet the call for investigations has been less effective in identifying and achieving needed changes on those aspects than on the technical countermeasures. This
article discusses a possible method for avoiding the recurrence of accidents like this one, with a main focus on its sociotechnical and human behavioral aspects.

In the author’s view, such human behaviors at many different levels are closely connected with so-called information asymmetry, which is interpreted as a source of social problems widely observed in information societies. One of the objectives of this article is to explore a method for avoiding the repetition, centering on management of the information asymmetry.

1.1. Why Were Only the Fukushima Daiichi Units 1–4 Fragile?

The Fukushima Daiichi accident raises a fundamental question: Can nuclear reactors be technically managed for power production while also providing adequate protection against extreme natural hazards on the scale of the 3.11 tsunami? This author’s answer is definitely “yes.”

The capability of managing an extreme natural hazard of this scale was demonstrated by the other NPPs, located on Japan’s northeast coast, which eventually were maintained safely, in spite of being impacted by a tsunami of nearly the same size, almost simultaneously with the tsunami that struck Fukushima Daiichi, on March 11, 2011. This fact straightforwardly demonstrates the feasibility of technical measures for protecting nuclear reactors from that size of tsunami.

One of the most valuable lessons learned from that factual experience is the vital importance of power supply at such critical emergencies.

A question that can be asked is: Why were only the emergency power supply systems employed at Units 1–4 of Fukushima Daiichi so fragile against the inundation? Among many explanations, the most noticeable is that little consideration had been given to the redundancy, in particular, the defense-in-depth with diversity of the emergency power supply system.

In Units 1–4, all the emergency diesel generators, including the backup generators, together with their switchyards, were situated at such a low elevation as to be entirely defenseless against the inundation. There was no engineered scheme to protect against this common-cause failure.

In Units 5 and 6 of Fukushima Daiichi, one out of five emergency diesel generators was not water cooled but air cooled, and was situated with the switchyard at a higher level. Only that single higher-level air-cooled generator was available after the inundation. Just by virtue of that availability, the reactor operators successfully maintained the safety of both Units 5 and 6. This experience reemphasizes the essential importance of redundancy with diverse power supply systems, which can protect against common-cause failures.

1.2. How to Manage a Low-Probability, High-Consequence Natural Event

A further question arises: What tsunami size should be considered as the design basis event? As is described below, the 3.11 tsunami obviously should have been included within the design basis. There, however, still remains a fundamental issue of how extreme natural events should be addressed in terms of reactor safety. This is related to a longstanding issue: How safe is safe enough, with a particular concern on low-probability, high-consequence risks? One of the pioneers raising this fundamental question was Alvin Weinberg, who floated an idea of trans-science, and considered a severe reactor accident as representative of a trans-scientific question.

Unless specific consideration is dedicated to such trans-scientific aspects, the Fukushima Daiichi accident will never be an epoch-making event from

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1 Those NPPs are the Onagawa Units 1–3 of Tohoku Electric Power Co., the Fukushima Daiichi Units 5 and 6, Fukushima Daini Units 1–4, and the Tokai Unit 2 of Japan Atomic Power Co. In total, there were 14 NPPs in the eastern coast region of northern Japan, and only four out of 14 reactors—Units 1–4 at Fukushima Daiichi—were damaged by the tsunami. The reason for the remaining 10 reactors’ survivals is clear: the safety of those plants was maintained, although in some cases barely maintained, by ensuring the supply of electric power, while the means for ensuring it varied from plant to plant. In the case of Onagawa, all the NPPs retained the function of the emergency diesel generators, mainly because the platform elevation of the reactor facility buildings was above the tsunami height, albeit by only about 1 m.

2 The operator cross-tied that single generator to provide sufficient AC electric power for those two units to place them in a safe shutdown condition. The situation facing the operators was extremely critical. They had to work in the dark, through the rubble, with limited instrumentation and control measures to use. See Ref. 6, p. 9.

3 In 1972, Alvin Weinberg wrote a well-known article, entitled “Science and Trans-Science,” in which he mentioned: “Many of the issues which arise in the course of the interaction between science or technology and society—hang on the answers to questions which can be asked of science and yet which cannot be answered by science. I propose the term trans-scientific for these questions.” One of his representative examples of trans-scientific questions is the probability of extreme improbable events, such as a catastrophic reactor accident.
which society has the opportunity to learn about the essence of what caused the accident to prevent its repetition. This article is an attempt to give such consideration.

In trying to learn about the essence of such a tragedy, what should be examined above all is the question of why Japan was unable to manage such fundamental issues adequately. As is mentioned in the investigative committee reports, the technical reason for that is primarily due to the failure to consider and incorporate into its safety decisionmaking the scientific findings and past experiences in overseas nuclear plants. In view of its interconnection with the trans-scientific aspects, i.e., sociotechnical or human behavioral aspects of the accident, a further in-depth inquiry about the failures is required. Thus, in what follows, such aspects of the accident are explored, enabling a discussion—with the aid of behavioral science theories—of possible ways for managing those aspects to prevent a repeat occurrence.

2. SOCIOTECHNICAL CHALLENGING ISSUES

2.1. Reflection upon New Scientific Findings on Extreme Natural Events

Let’s consider here why Japan failed to learn adequately from past scientific historical records of significantly great tsunamis; for example, a tsunami of similar magnitude following the Jogan Earthquake (M8.0–8.5), also on Japan’s northeastern coast in the year 869 AD, was not taken into account in designing the Fukushima Daiichi NPPs.

In the early 1960s, when TEPCO first designed the Fukushima Daiichi NPPs, there were no scientifically proven geologic indications around the location to suggest historically significant tsunamis, including the Jogan tsunami. Thus, the maximum height of a potential tsunami assumed in designing the NPPs was only about 3 m above sea level, which was derived from the historical record observed at the location in the 1960 Chile earthquake. Nevertheless, the elevations at Fukushima Daiichi where the reactor buildings were actually constructed are 10 m for Units 1–4, and 13 m above sea level for Units 5 and 6, respectively.

In Japan, the safety requirement against tsunamis was first specified in the Regulatory Guide for Reviewing Safety Design for Light Water Nuclear Reactor Facilities established in 1970. In the Guide, tsunamis were considered as one of the natural events to be taken into account and the ability to withstand the maximum possible tsunami force, predicted from past records, was required. The conformity of safety design against tsunamis of Fukushima Daiichi was then rechecked by the regulatory authority. This fact implicitly indicates immaturity around the 1960s and the 1970s of safety considerations concerning potential risks from tsunamis.

2.1.1. Remarkable Progress in Japan’s Seismology

After the 1995 Hanshin Awaji Great Earthquake (M7.3), which caused approximately 6,500 deaths, Japan launched a national project for implementing nationwide geological investigative studies on seismic activities to assess the risks of potential earthquakes and tsunamis. Since then, there has been remarkable progress with a great number of new scientific findings.

In TEPCO, following this progress, a study was conducted to reevaluate reactor safety against earthquakes, including against tsunami impacts. As a matter of fact, prior to the accident, the company itself had obtained a preliminary trial study result indicating that the maximum possible tsunami would be far beyond the platform elevation. After February 2002, when the Japan Society of Civil Engineers released its new recommendation on a computational method to assess the magnitude of potential tsunamis, TEPCO took a certain action to strengthen the measures protecting against tsunami attacks at the Fukushima Daiichi site, revising the maximum possible tsunami to be 5.4–5.7 m above sea level instead of the original assumption of 3 m. Until this point in time, no scientific information had been provided to show the possibility of an occurrence of a tsunami originating from the Fukushima Daiichi offshore seabed dislocation. The 3.11 tsunami occurred due to 500-km-long dislocations abruptly created by an earthquake under the seabed, a portion of which was located offshore of the Fukushima Daiichi site. On the other hand, a progress report of the national project launched after the 1995 earthquake disclosed its view in July 2002, that there is a possibility of an occurrence of earthquakes of M8.2 anywhere along with the Japan Deep Trench, including offshore of the Fukushima Daiichi site. In addition to that view, some scientific studies performed

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4 In designing the Onagawa NPPs in the late 1970s, located a few hundred kilometers north of the Fukushima Daiichi site, Tohoku Electric Power Co., the owner of the NPPs, conservatively decided that the elevation of the plant facilities building was to be about 15 m above sea level, taking into account a Jogan-like maximum possible tsunami, because the Onagawa coast is well known as a tsunami-prone region.

5 After February 2002, when the Japan Society of Civil Engineers released its new recommendation on a computational method to assess the magnitude of potential tsunamis, TEPCO took a certain action to strengthen the measures protecting against tsunami attacks at the Fukushima Daiichi site, revising the maximum possible tsunami to be 5.4–5.7 m above sea level instead of the original assumption of 3 m. Until this point in time, no scientific information had been provided to show the possibility of an occurrence of a tsunami originating from the Fukushima Daiichi offshore seabed dislocation. The 3.11 tsunami occurred due to 500-km-long dislocations abruptly created by an earthquake under the seabed, a portion of which was located offshore of the Fukushima Daiichi site. On the other hand, a progress report of the national project launched after the 1995 earthquake disclosed its view in July 2002, that there is a possibility of an occurrence of earthquakes of M8.2 anywhere along with the Japan Deep Trench, including offshore of the Fukushima Daiichi site. In addition to that view, some scientific studies performed.
In responding to that preliminary result, TEPCO took some action. For example: (1) it opted not to disclose this information to the public but instead share it privately with only limited number of regulatory people to start maneuvering for a compromise with the regulator; (2) it entrusted the Japan Society of Civil Engineers to look into the scientific method for understanding the potential impact of future tsunamis at the Fukushima site; and (3) it created an in-house task force for making further investigation.⁶

2.1.2. The Organizational Reasons for Lack of Sufficient Progress

The actions mentioned above, however, were entirely insufficient. One of the possible reasons for this is that in those years a much more urgent nuclear matter was facing TEPCO. This was the urgent need for reevaluation of seismic safety for the Kashiwazaki-Kariwa NPPs, where, due to the 2007 Chuetsu Oki Earthquake (M6.8), massive ground motions far beyond the design basis had struck the reactor buildings, although there was only a modest effect on the safety of seven reactors at the site. Since the earthquake, the company performed extensive work to reevaluate that plant’s seismic safety, something that was of highest priority in order for the regulator to permit the company to resume reactor operations. In fact, the resumption did not occur until 2010.

In the 2013 TEPCO self-investigation report,⁷ a root-cause analysis showed the following factors to be the underlying reasons for the failure to reflect on the new scientific findings or the reluctance to learn proactively from the findings:

(1) lack of safety consciousness,

(2) insufficiency of competence, and

(3) inadequacy of communication with the public and the regulator.

To be specific, first, there had been an overconfidence about tsunami safety in the company’s Nuclear Power Division. The Division had arbitrarily convinced itself that it would be very unlikely for such serious inundation to strike the NPPs; it had brushed away the fact that, with the recent scientific observations in mind, a Jogan-like tsunami is predicted as frequently as once every 1,000 years, while the scientific information available in the past had not necessarily been reliable enough for making a good estimate as to the ability of the plants to resist such tsunami impact.⁷

Second, the Division was too incompetent to take an initiative on its own for making a scientific assessment of the potential impact of such huge tsunamis on the NPPs. Instead, it left it largely with external organizations such as the Japan Society of Civil Engineers.

And third, the Division’s concern was not as dedicated to the safety of the reactors following a large tsunami as it was to concerns about jeopardizing the confidence of the local community and general public if the potential tsunami risks were made apparent.

What is to be noticed here is that the company’s decision on tsunami safety was not made by TEPCO’s top management but solely by the Division because the issue was conspicuously nuclear specific and was therefore perceived by the top management as a subject to be dealt with within the Division, even though there was a potentially fatal risk to the company’s future from a direct impact of a tsunami far beyond the design basis.

2.1.3. Governmental Infallibilities

In addition to the above-mentioned TEPCO situations, there is another sociotechnical problem on the part of the Japanese regulator, which, by and large, is also reluctant to proactively reflect upon

⁶See TEPCO,¹⁴ pp. 27–33.

¹⁸The method used in the national project to assess the potential hazards associated with the tsunamis on the east coast of northern Japan was based upon measurements systematically obtained only for the last 400 years because information from earlier times was limited. Examining the scientific conclusions of recent studies, however, it is clear that the likelihood of a Jogan-like tsunami is on the order of once every 1,000 years, indicating the need to repostulate it as a design basis scenario for safety assessment.
new scientific findings. Traditionally, Japanese regulations, either nuclear or nonnuclear, are based upon the notion of so-called governmental infallibility, which implies that a governmental decision must be absolutely correct whenever made. In the ANS committee report, the Japanese regulatory system is seen to be driven more by process than by analysis. It is deeply connected with this tradition; the process in many cases is primarily dedicated to defending the notion of governmental infallibility.

In terms of the potential risks from tsunamis, when being questioned at a meeting in the Diet in 2006, the regulator expressed its view that the safety of the reactors could be maintained by conforming to a predetermined operational manual for accident management, even if the inundation were beyond the design basis. This view, largely arising from the notion of governmental infallibility, implicitly suggested that there was no need to order licensees to take on additional actions for enhancing the safety of the reactors against tsunamis. It disregarded the potentially devastatingly disastrous situation possibly caused by a huge inundation, which would make it difficult to implement the accident management operations. Because of the traditional nature of Japanese culture in this regard that has developed over the past hundreds of years, this problem might not be easily overcome in the foreseeable future.

One of the crucially challenging issues is, therefore, how to maintain and continuously improve reactor safety under the assumption that the Japanese regulations cannot be completely disconnected from the notion of governmental infallibility, even when a new scientific finding occurs that is not consistent with a past governmental judgment.

2.2. Learning About Overseas Reactor Accident Risks

2.2.1. The 1999 La Blayais Flooding Event

Another challenging question to be addressed is why TEPCO failed to gain insight from the experiences of overseas NPP accidents/incidents. In particular, a severe incident took place in December 1999 at the La Blayais NPPs, located at an estuary in southwestern France, due to a very large beyond design basis flood producing inundation coming over the dyke. Fortunately, some pumps and power generators were not damaged but operated to maintain plant safety. A lesson learned from the event, however, was that risks similar to the flooding-inundation risk at Fukushima Daiichi were identified by the French regulator and the French power company:

1. the loss of the water supply by flooding of the pumping equipment or large-scale arrival of detritus;
2. the loss of off-site power supplies by flooding of the switchyard;
3. flood-related loss of equipment important for safety; and
4. prolonged isolation of the site, in particular making it impossible to relieve the shift crews, refuel the emergency generator sets, or bring in mobile emergency resources.

No doubt, much less damage would have been incurred at the Fukushima Daiichi site if some of these risks had been seriously recognized by TEPCO and/or the Japanese regulator, although the catastrophic circumstances facing the plants at Fukushima Daiichi were much worse.

2.2.2. Accident Management and Emergency Preparedness

More broadly, a number of actions for managing severe accidents had been taken internationally for enhancing overall reactor safety, reflecting the lessons learned from the 1979 Three Mile Island (TMI) and the 1986 Chernobyl accidents. In Japan, however, the lessons had not been as thoroughly learned as in other countries.

As a consequence of discussions over many years about these earlier accidents, the International Atomic Energy Agency (IAEA) gave recommendations to the Member States on the need to advance the concept of defense-in-depth from the conventional three layers (prevention of failures, mitigation of an accident sequence once it has begun, and features to reduce consequences) to five layers, adding accident management for beyond design basis accidents and emergency preparedness. But, Japan had been reluctant to adopt this advance.

The reasons for such reluctance are sociotechnical as well. Among others, Japanese industry and the regulator had dismissed the TMI-like and Chernobyl-like types of severe accidents, primarily because both accidents arose from internal causes,

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8See ANS, (4) p. 28.
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exacerbated mainly by human factors, and the Japanese nuclear community had trusted in its own human competence too much.

There is also another reason for reluctance. Although Japanese NPPs are sited in populated areas, historically, a convincing argument had been made to the nearby residents and the local governments: that severe accidents requiring emergency evacuation would never happen. As a matter of fact, a stricter protocol for an emergency may not be so easily implemented as it would be in less populated sites overseas. From this, the regulator and licensees arrived at a compromise solution: accident management would not be required in terms of regulations but only suggested to be implemented voluntarily by licensees.

2.2.3. A Further Reason for Reluctance to Use Proactive Reflection—An Internal-Consensus-Based Society

A root cause for necessitating such a compromise might originate in Japan’s uniqueness as being an internal-consensus-based society. In other words, a consensus for using nuclear power was built on a very subtle sociopolitical balance between the central government, local communities, and power companies. If the balance is lost, it usually takes an extremely lengthy process to rebuild another consensus.

For instance, if something related to safety requires the company to shut down a reactor, it often takes a long time for the company to be permitted to resume operation by the local government as well as by the regulator. In most cases, this has little to do with technological issues but mainly with internal consensus rebuilding. Under such circumstances, power companies often made the argument that there is no earnest or urgent need to learn from the experiences abroad.

Because of this country-specific reason, Japan has been extraordinarily reluctant to reflect proactively upon the experiences in non-Japanese countries, and, more or less, this is also true concerning failures to proactively learn from new scientific findings.

Actually, in the 2013 report, TEPCO explicitly realizes this point and describes it as a lack of adequate risk communication; it delineates an action plan to extricate itself from “the thought-stopping patterns,” a situation in which it is assumed that, if risks are announced, requests for excessive countermeasures will be demanded by regulators and site communities, necessitating a reactor shutdown. Without innovative improvement of risk communication in this regard, Japan will never bring about a change so that proactive reflection about new scientific findings and operating experiences overseas will occur.

2.2.4. The USNRC Actions After the Events of 9.11.2001

There is one more overseas experience with accidental measures Japan missed: the countermeasures the USNRC employed after the terrorist event of September 11, 2001, which required reactor licensees to develop and implement guidance and strategy intended to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities under circumstances associated with the loss of large areas of the plant due to fire and explosion. The requirements include establishment of mobile extra power sources and extra water supply sources.

It is reported that because of the security countermeasures against terrorists, this action was confidentially introduced by the USNRC to the Japanese regulator around 2003. If seriously implemented, the accident at Fukushima Daiichi might not have been as serious as it was. Unfortunately, that was not the case, probably due to an optimistic perception of the regulatory body on the likelihood of such serious terrorist attacks in Japan.

2.3. Strengthening the Safety Culture

Every time serious reactor incidents or accidents take place, the need to strengthen the safety culture is asserted, and such is the case for the Fukushima Daiichi accident, too.

The concept of safety culture was introduced in 1991 by the IAEA, as a lesson from the 1986 Chernobyl accident, and the definition given there is “the assembly of characteristics and attributes in organizations and individuals which establishes that as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance.”

A question arises: Why was the insufficiency of safety culture in TEPCO revealed seriously in the accident? Ironically, the answers to such questions are described in the IAEA publication. First, the IAEA

9 See U.S.NRC, p.47.
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heeds warnings that the biggest danger is to oversimplify things in our minds, tempting us to say that culture is just “the way we do things around here,” or “our basic values,” or “our rituals,” and so on. Because the definition can seem like spiritualism or moralism, there is always a risk of oversimplification and, unfortunately, Japan’s utility companies’ perception has fallen into that pattern.

Second, the IAEA mentions that the view of people can be influenced by how they are treated in an organization: if the view is that people are undisciplined and self-interested, there will be many controls placed upon them. If people are regarded as interested in realizing their potential through development, as well as being regarded as trustworthy, they may be managed in a more flexible way that empowers them to undertake greater responsibility. However, in Japan’s organizational situations, where such workers’ capability is regarded as relatively high, the safety culture issue has not been properly perceived. Instead, top management has not taken a strong leadership in implementing safety culture but has left it without well-prescribed definition, too much within the people’s discretion, as to whether or not to assume greater responsibility.

As a whole, not merely a spiritual requirement but a certain institutional arrangement is necessary for actions to strengthen safety culture to become effective. This subject will be touched upon later.

2.4. Reinforcing the Regulations

2.4.1. Independence of the Regulator

Obviously, a revolutionary reform of Japan’s nuclear regulatory system was strongly demanded following the Fukushima Daiichi accident. In September 2012, a new regulatory body, called Nuclear Regulation Authority (NRA), was established as an independent regulator.

Prior to the accident, the Japanese regulator, the Nuclear and Industrial Safety Agency (NISA), had been organized within the Ministry of Economy, Industrial Trade and Industry (METI), which is in charge of promoting the nuclear industry.

Many critics have viewed this lack of regulatory independence as one of the major reasons for this accident. The main message in the Japan’s Diet Committee report that investigated the accident, for instance, is that the accident stemmed mainly from the country-specific regulatory weakness, i.e., the regulatory capture by licensees.

In 2007, before the accident, the IAEA/Integrated Regulatory Review Service (IRRS) mission to Japan specifically pointed out the intertwined nature of the responsibility for nuclear regulations, addressing the weakness of NISA belonging to a promoting agency, METI, and the need for clarification of the roles of NISA and the Nuclear Safety Commission (NSC) of Japan.

A question to ask is why had Japan employed such a unique regulatory system for so long? First, historically and globally, nuclear regulatory bodies were commonly established within promoting organizations. For example, in the United States, the Atomic Energy Commission was for many years in charge of both regulations and promotion of the nuclear energy industry. This might be the case for several reasons: one of which may be that due to the political aspects, the development of nuclear technology would not be possible without governmental leadership, and, on the other, owing to the lack of technological expertise in the government, the regulations would not be possible without the substantial help of industry.

2.4.2. Regulatory Competence

But, more importantly, with the limited availability in the government of human and budgetary resources in mind, it would be difficult for an independent regulator to develop and maintain its competence, if independence means self-sufficiency in that respect as well. This competence management issue is sharply described in Blandford and May: “Recognition of the need for a strong, competent and independent regulator has not come easily to most countries and is not always and everywhere accepted in practice to this day. In particular, independence

10 See IAEA, p. 3.
11 See IAEA, p. 14.
joined with the resources sufficient to competence faces continuing tensions from operators.”

This suggests the necessity of managing the regulatory independence issue together with the competence issue. Some major nuclear states with not only a civil program but also a defense program might have an advantage in this regard. In the United States, for instance, the human resources in the defense program are often made available to the regulators and the industrial sectors, hence making possible the management of both the competence and the independence aspects. Japan is not such a dual-program country but hopefully can afford to manage the issue on its own, as one of the most advanced civil nuclear states. For most of the new entrants into the nuclear power field, however, the only way to accomplish this is to provide international assistance.

2.5. Command-and-Control System

In the course of managing the Fukushima Daiichi accident, the command-and-control system in Japan was criticized, nationally and internationally, in a number of aspects: unclear definition of responsibility within the management structure, and inadequate information dissemination, for instance.

In reality, there certainly were confusions in the system. When faced with such an entirely unprecedented emergency situation, individuals, of both the government and the TEPCO, were so confused that some of them attempted to take actions beyond their prescribed capacity and some others were unable to discharge their own responsibilities in situations where there was a voracious need for more urgent actions.

These types of responsibilities had not been assumed in the emergency management plan previously established, but rather the omissions confused the command-and-control setup that should have been implemented in this extremely catastrophic situation.

Also an issue revealed from managing the accident was a dilemma of information dissemination: swiftness or accuracy? In the Fukushima Daiichi accident, the decisionmaking on this dilemma was by the then Chief Secretary of the Cabinet, the governmental spokesman in Japan, and he apparently prioritized for accuracy.

It is likely that owing to the government’s accuracy-first policy, the information was not disseminated in a timely fashion concerning the amount of environmental radioactivity estimated from the measurements and/or computations and the extent of the damage of the reactor core fuels, scientifically inferred from the time elapse since the loss of coolant, because it took a great deal of time to confirm the facts with enough accuracy for the government. As a result, the delayed provision of related information meant that the public lost trust in its reliability.

An unequivocal vulnerability revealed from the accident was the defect in suitable communication management between the government and the operator (TEPCO), and this presented the need to reconsider how to make provisions for performing that function adequately and practically.

The ANS report provides an interesting observation on this, from the viewpoint of the societal context for the accident. It describes “what we know today is that this is a complex story of mismanagement, culture, and sometimes even simple errors in translation, all amidst a voracious need for immediate information by governments and media.”

In the ANS report, a quintessential point is addressed: “it [the reason why the Japanese government chose not to follow its established process for managing a nuclear crisis] resolved around personalities; a widespread distrust of TEPCO, and a general low regard of the Japanese regulatory system, which was driven more by process than by analysis.”

As described, the issue is interconnected with many factors, suggesting the need to rethink it not only as a command-and-control system alone but also as an issue of the integration of the whole system including the regulations.

3. MANAGEMENT ISSUES WITH HUMAN BEHAVIORAL SCIENCES

3.1. Managing Operators’ Self-Actions for Continuous Improvement of Safety

A cross-cutting issue lies among the sociotechnical or human behavioral challenges mentioned above. That issue is the overriding importance of the operator’s self-actions for continuous improvement of nuclear safety. The vulnerability in Japan’s management system that the accident revealed was the ambiguity of responsibility for ensuring safety: who within the company is responsible for assuring safety from the threat posed by a large tsunami; what is the role of top management in ensuring nuclear safety;

14 See ANS, (4) p. 27.
15 See ANS, (4) p. 28.
what is the difference in the responsibility between the operator and the regulator; and so forth.

3.1.1. Actions Concerning the Prime Responsibility of Ensuring Nuclear Safety

One of the fundamental principles for ensuring nuclear safety is that the prime responsibility lies with the operators. What the Japanese nuclear industry should consider above all things is the prerequisite nature of this principle of prime responsibility of the operators. This implies formulating and implementing action plans and, in particular, pursuit of continuous improvement of nuclear safety as a separate endeavor from normal operational activities.

If this had already been the case, the new scientific findings and overseas experiences would not have been dismissed. Keeping in mind the repeated improper behavior of the industry that occurred, whenever serious nuclear incidents happened, it is a truly challenging issue to establish effective and responsible safety management by the operators. Appropriate innovative actions must be planned and implemented in response to new scientific findings and overseas experiences.

First of all, a management system for developing and maintaining safety culture within the company has to be rebuilt, under the top management’s deep commitment to its own policy about self-endeavors for the continuous improvement of safety. As was mentioned before, however, the concept of safety culture is inclined to be dismissed as a kind of spiritualism, oversimplified as “the way we do things around here,” or simply “our rituals.” To avoid this, a very special sociotechnical arrangement is needed.

3.1.2. Individual or Self-Organizational Levels

On an individual level, if one is rewarded by top management, innovation, implementation, and maintenance of best practices would probably be encouraged. This is a method commonly employed in quality control.

Historically, Japanese industry learned the theory of quality control from a well-known American scientist, W. Edwards Deming, and thanks to his enthusiastic instruction, the industry overwhelmingly succeeded to produce high-quality and cost-effective goods. One of the things Deming earnestly elucidated was the usefulness of a reward system, since he realized the Japanese had not rewarded each individual for his or her specific contribution nor cherished individual competition. In learning lessons from the Fukushima Daiichi accident, Japan should reconsider Deming’s suggestion in planning actions for enhancing nuclear safety at an individual or self-organizational level.

And also some concrete measures should be taken. In a rebuke-prone society like Japan, where errors and mistakes, albeit minor, are often magnified by the public and the regulator—particularly if concerned with nuclear safety culture—some specific measures should be concretely considered to manage this aspect of the culture, in addition to measures to assure and seek to improve best practices rather than retaining traditional practices.

For example, in operating reactors, a self-organizational cross-checking system using computerized knowledge management tools would be helpful for reducing the occurrence of human errors in terms of quality management, and an operational data recording and storing system with very reliable traceability, such as a flight-recorder system, would also be useful for the minimization of data falsification.

As has been observed often thus far as a scandal of inappropriate treatment of information in industrial companies, for instance, there certainly is a risk in a complex system—such as a management system for nuclear reactor operations—that the complexity allows for falsification to go undetected. Basically, the risk is associated with the so-called information asymmetry inevitably existing between various levels, which will be touched upon below.

3.1.3. Organizational or Institutional Levels

As far as institutional arrangements at the organizational level of safety culture are concerned, a number of good suggestions can be learned from U.S. practice.

For instance, the USNRC implements performance-based regulation, where the so-called reactor oversight process is introduced using performance indicators. The indicators provide a measure of licensee performance, encouraging appropriate licensee behavior as well as identifying problem plans, and the US NRC inspections depend on its assessment reports on performance indicators. As a consequence, it helps a great deal with giving an incentive to licensees so that they may achieve high performance with their own self-improvement efforts. As such, institutional arrangements providing
a tangible benefit for developing and maintaining the safety culture play a significant role in making the safety culture management system as robust as possible.

In the United States, a great incentive is also institutionally provided by the Institute of Nuclear Power Operations (INPO), which was established in 1979 by the U.S. nuclear power industry in response to recommendations by the Kemeny Commission Report\(^\text{23}\) that investigated the TMI accident. The institute is funded entirely by the U.S. nuclear industry.\(^\text{24}\)

INPO is intended to promote operational excellence and, in so doing, it established a unique system that is balanced between transparency and privacy. To be specific, INPO performs plant evaluation at nuclear sites to identify both strengths and areas for safety improvement. The results of these evaluations are used for information sharing with other plants, but are not open to the public. On the other hand, actual performance results, including all incidents, are made public, demonstrating the fulfillment of the accountability to the public of this entirely utility-funded organization.

Despite certain concerns from critics over the nonopenness of INPO, this unique system is designed and has functioned so that, under the firm commitment of the company with the prime responsibility for ensuring safety, criticism can be uninhibited and action can be taken in a timely manner without fear of misinterpretation.\(^\text{25}\)

Taking into consideration INPO’s remarkable success as a self-regulator, the Japanese power industry recently formed a new organization, called the Japan Nuclear Safety Institute (JANSI), following the idea of INPO, in the wake of the accident.\(^\text{26}\) It is expected that the new organization will play a similar role to INPO, particularly in terms of giving a tangible incentive for operators to maintain a proper safety culture.

This, however, does not necessarily suggest JANSI should be a copy of INPO. INPO was created as nuclear power’s collective conscience, compared to the pre-TMI U.S. nuclear industry, which was fragmented and behaved like an “island unto it-

\(^{16}\)In March 1993, the Supreme Court ended Ralph Nader’s nine-year legal battle to make INPO documents public. The Court in effect upheld INPO’s secretive ways, and that secretiveness, more than anything else, is what nuclear power critics have found most troubling about INPO. See Rees,\(^\text{25}\) p. 118 and also Blandford and May,\(^\text{21}\) p. 32.

\(^{17}\)See Rees,\(^\text{25}\) pp. 41–43.

\(^{18}\)See Blandford and May,\(^\text{21}\) p.19.
3.2. Managing the Regulations

3.2.1. Public’s Strong Demands for Strong Regulator

After the accident, there has been an earnest cry for stronger regulation from the Japanese people, including politicians and mass media as well as the general public, who unanimously think that nuclear safety must be ensured primarily by the regulations, not by the operators’ self-endeavors for safety improvement. In responding to the cry, the Chair of the new regulatory body, NRA, made a statement that the new body is aimed at being the strongest in the world. In actuality, the regulator intends to promulgate the most stringent safety requirements of any country globally. The movement toward the strongest regulator not only brings about overly prescriptive regulations but also provides a global concern for jeopardizing public confidence in international institutions that have been developed to ensure a high level of nuclear safety.19

3.2.2. Transformation of U.S. Nuclear Safety After TMI

To manage the issue of the public’s strong demands for a strong regulator, Japan should learn from U.S. experience, especially from the transformation made after the TMI accident. The post-TMI history of the U.S. system for ensuring nuclear safety has been outstandingly described by Joseph Rees.25

The worldwide nuclear industry, in the aftermath of the Fukushima accident, has been growing increasingly impatient with the way recent developments have been communicated. At the heart of the problem has been the use that TEPCO and Japan’s NRA have made of the International Nuclear Event Scale (INES) to report on the severity of storage tank leaks that were uncovered in late 2013. “In Japan we have seen a nuclear incident turn into a communication disaster,” grumbled Agneta Rising, director general of the World Nuclear Association (WNA)—“Mistakes in applying and interpreting the INES scale have given it an exaggerated central role in coverage of nuclear safety.” The WNA says that the NRA was warned by the IAEA that: “Frequent changes of rating will not help communicate the actual situation in a clear manner.” Yet this is exactly what happened as news of the tank leaks unfolded. The leaks were ultimately categorized as Level 3 on the INES scale, or “serious incident.”29

The U.S. system for ensuring nuclear safety was transformed gradually in the wake of the TMI accident so that it might be fundamentally based on self-improvement within the industry, being supported with a risk-informed, performance-based regulation. However, it has taken time to reach today’s level of maturity, through a number of learning-by-doing steps.

Over the past many years, Japan’s old regulator, NISA, also took an approach to introduce the idea of risk-informed, performance-based regulations. The approach, however, was not sufficiently based on self-improvement within the industry, and therefore had little effect in stimulating the operators’ self-action for enhancing safety. The approach being taken by the new regulator, NRA, appears to be similar because it has little intention of challenging the nation’s emotional perception that the regulator must always triumph over the industry.

With the long U.S. history of such transformation in mind, Japan will have to be patient in working to transform its system so that it may ultimately mature to be similar to the current U.S. system, which is well coordinated between the industry and the regulator, dubbed by Rees “communitarian regulation.” A good indication is illustrated in the NRA’s approach to the review of potential seismic sources of geologically active fractures. In responding to the strong criticism received after the accident, the approach is aimed at being so rigorous that all the uncertainties associated with geological assessment must be treated most conservatively, regardless of their potential impacts on reactor safety. It appears as if the NRA will pursue something like “absolute safety” but only from the standpoint of assessment of geological active fractures. A number of meetings to discuss NRA’s review approach have been repeatedly held open to the public; however, the NRA has seemed to shift, albeit very slowly, to a more scientifically reasonable approach, reflecting a variety of different scientific views provided at the public meetings.

Although this is a lengthy process requiring patience, the lengthy time cannot be avoided in resolving sociotechnical aspects of regulation-related lessons learned from the accident, especially when the public maintains a strong demand for stringent regulations. A key element of this process is its transparency; in this particular case, the NRA deliberation process is open to the public with considerable traceability.
3.2.3. Self-Actions for Improving Regulations

How to maintain and improve regulatory competence and preclude regulatory capture by licensees is certainly one of the most crucial issues. When the author was Chair of NSC and held a variety of meetings to exchange information with the regulator, NISA, it was recognized that the transparent meeting process with traceability is also useful for improving competence because it provides a good opportunity for the regulatory staff to demonstrate their own capability.

In addition to that, when necessary to avoid complacency, the regulatory staff must be given an opportunity to study the field work and new technologies developed in the industrial sectors, and to participate in a training program with the highest transparency, as part of communitarian regulations.

Naturally, how to strive for advancing regulatory methods is also indispensable if the regulator is to develop the scientifically most reasonable regulations. One of the most effective methods is based on active offers by operators and/or vendors to advance ideas to the regulator with the highest transparency. For instance, the USNRC’s annual regulatory information exchange meeting with the industry and the public seems to make remarkable sense in this respect.

Then, what is crucially important in managing the regulations is how to make a convincing argument of regulatory pertinence. Operators’ self-assessment of safety margin has been increasingly required for this purpose. In terms of the extreme natural events, the USNRC required each licensee to implement the Individual Plant Examination (1988) and later the Individual Plant Examination of External Events (1992), and as far as I understand, those helped a great deal in improving the safety.\(^{30}\)

In France, responding to lessons learned from the 1991 La Blayais serious incident, the concept of reviewing safety margins was introduced before the Fukushima Daiichi accident, while actual implementation of so-called stress tests to look into the cliff edge of safety was motivated throughout Europe immediately after the Fukushima Daiichi accident.\(^{31}\)

Unfortunately, such practices as reviews of safety margins were not done in Japan in time to motivate action to counter the threat of a common-cause failure from a large tsunami at Fukushima.

Also, the regulators should encourage operators’ self-actions for continuous improvement of safety. Performance-based regulations and periodic peer reviews should be implemented in this context.

Finally, how regulators develop new knowledge and learn about new scientific findings, precluding regulatory capture by licensees, is one of the major lessons. According to the author’s personal experience as Chair of NSC, it requires a specific institutional arrangement for facilitating objective discussions in the realm of science, and also for allowing operators’ decisionmaking at their own cost, as well as ensuring the transparency and accountability of learning processes. This is related to the information asymmetry issue, which is described in the following.

3.3. Managing Information Asymmetry

There is a fundamental issue that influences the management of operators’ self-actions for continuous improvement of safety and the management of regulations. That is the so-called information asymmetry.

3.3.1. Social Problems Due to Information Asymmetry

Information asymmetry means a disparity in the quantity and quality of information between information suppliers and demanders, in which, usually, the suppliers’ dominantly superior to the demanders’, as, in many markets, sellers are better informed about product quality than buyers. It has been recognized in human behavioral sciences that information asymmetry causes many social problems, and the question of how to manage the problem is an increasingly important subject. A Nobel Prize in economic sciences in 2001, for instance, given to three prominent scientists, was specifically dedicated to their outstanding achievements in behavioral economics with asymmetric information, in which fundamental questions are studied, such as: What happens in the market inherently with information asymmetry and what can better-informed or less-informed agents do to improve their market outcome, proving that some institutional arrangements might be necessary to improve the outcome?\(^{32}\)

Nuclear safety is an excellent example for such considerations because, as is unequivocally revealed in the Fukushima Daiichi accident, the cause of the accident was closely related to communication matters that are profoundly associated with information.
asymmetry between industries, regulators, and the general public.

3.3.2. The Advantageousness of Public Participation

Alvin Weinberg addressed the issue of information asymmetry between scientists and nonscientists, where he asserted the advantage of public participation in trans-scientific issues.\(^{20}\)

The advantage of public involvement is also demonstrated in the market with information asymmetry. To be simple, in used car markets, at any given price, a seller of a high-quality car is less inclined to sell than a seller of a low-quality car, and buyers anticipate it, suspecting that the car offered in the market is of low quality. This rational suspicion depresses price, which further discourages sellers of high-quality cars, who continue to leave the market until mostly low-quality cars remain for sale. Such a downward quality bias is called adverse selection.\(^{33}\)

In the market of an Internet car auction, however, this adverse selection problem is considerably resolved since the suspicion between sellers and buyers is alleviated remarkably with tremendously increased information enabling agents to make reasonable evaluations on the pricing. The key element of this alleviation is, again, information transparency. Thus, transparency is not merely useful for confidence building but actually could play a significant role in solving a problem stemming from information asymmetry. The necessity of transparency in managing self-actions for continuous improvement of safety is to be understood in this way, and this understanding should be overriding emphasized in learning the lessons from the accident.

Thus the NSC established a policy for its deliberations so that the committee members included anti-nuclear scientists, the committee meetings were entirely open to the public, and the committee did not go fast but was patient enough to wait for scientists to reach a consensus. As a result, even though it took an additional five years, the NSC was successful in completing the deliberation with an agreement among the scientists with various views concerning how, from the reactor safety point of view, to deal with the trans-scientific issue of low probability, high consequence natural events. In the deliberation process, a lot of different views were provided by nonscientists at public hearings and through the Internet, to which the committee perseveringly responded, view by view.

In Japan, this was the first attempt of a governmental agency to draw a conclusion concerning a trans-scientific matter, holding nearly 100 meetings open to the public for deliberation and responding to comments from as many stakeholders as possible. From this, it was realized that this is one of the methods for reaching a consensus about a challenging issue such as a trans-scientific matter, recognizing the usefulness of a kind of communicative action in the public sphere, advocated by Jürgen Habermas,\(^{34}\) for instance, which is to use an arena for undistorted communication aiming at reaching a rational consensus.

However, it is not certain that the method is always effective for drawing a consensus from any discourses about trans-scientific issues. Rather, for some issues, it would probably need too long a time to reach a consensus in such a way that it might be useful for practical implementation.

Actually, in parallel with the NSC deliberation, there was a lawsuit charging that seismic safety was insufficient for the NPPs located in a very quake-prone region, Hamaoka of Chubu Electric Power Co. From the company’s point of view, it would have been preferable if the revised guidelines had been established much earlier so that the company might have taken some concrete actions for seismic safety enhancement, meeting the provision of the

\(^{20}\)See Weinberg,\(^{20}\) p. 220.
revised guidelines. That was not possible. However, some preliminary estimates about the revised requirements concerning the design basis ground motion, for instance, were able to be made within a certain reasonable range because the discussions at the NSC meetings were totally transparent and any company could make its own provisional assessment, assuming what it wished about the future possible revised requirements. As a matter of fact, the Chubu Electric Power Co. won the lawsuit mainly because of its own self-action for enhancing seismic safety.\(^{(35)}\)

3.3.4. Actions of a Better-Informed Agent

The issue of information asymmetry is related to the command-and-control system as well. According to behavioral science theory, the system must be designed and implemented assuming the existence of information asymmetry. The blunder of command-and-control during the 3.11 emergency was owing to the lack of such an assumption, which is deeply connected with the Japan-specific misperception of the public that nuclear safety must be ensured by the government, and not primarily by the operator.

Hence, of greatest importance, in addition to a continuous attempt to convince the public of the need to change its misperception, is that Japanese industry should recall again and, with the utmost effort, follow one of the recommendations given in the Kemeny report—which is now an international common understanding—about the following fundamental principle: “Responsibility and accountability for safe power plant operations, including the management of a plant during an accident, should be placed on the licensee in all circumstances. It is therefore necessary to assure that licensees are competent to discharge this responsibility. To assure this competency . . . the [regulatory] agency should establish and enforce higher organizational and management standards for licensees.”\(^{21}\)

With Japan’s long introvertive history since the 1979 TMI accident in mind, this is extremely challenging. Nevertheless, as a better-informed agent, the operator should take the initiative to demonstrate its competence utilizing many occasions, independent of the public’s perception, and it would probably make sense to encourage the general public to change its perception, even though this would take a long time. If this is the case, most of the weaknesses of the command-and-control system revealed in the 3.11 emergency would be resolved.

3.4. Managing Procedural Rationality

Alvin Weinberg insists on recognizing the limitations arising from depending on only scientists’ own views in considering a trans-scientific issue. A similar thought is a little more elaborately depicted in a broader sense from a social scientist’s view in Herbert Simon’s seminal work.\(^{(36)}\)

3.4.1. An Interaction with the Outer Environment

Simon writes: “An intelligent system’s adjustment to its outer environment (its substantive rationality) is limited by its ability, through knowledge and computation, to discover appropriate adaptive behavior (its procedural rationality).”\(^{22}\) According to Simon’s theory, there is an inevitable interaction between the inner and outer environments, accompanied by information asymmetry, and a pivotal issue is to enhance procedural rationality, developing some intelligent tools for helping make better decisions.

The key element here in terms of procedural rationality is the human behavioral approach to having an interaction with its outer environment in such a way that a certain specific consideration might be given to accommodate to the limitedness of its substantive rationality. In applying this to Weinberg’s trans-science, scientists need to interact with nonscientists and the general public at large, giving special consideration to accommodate to their own bounded nature in resolving a trans-scientific issue.

In this regard, Weinberg mentioned that the most science can do is to inject some intellectual discipline into the republic of trans-science.\(^{23}\) In view of the growing needs of dealing with trans-scientific matters, however, more active participation seems to be required. In other words, particularly important is not only the injection of some intellectual discipline but also the development of an intellectual strategy that may facilitate the public involvement and thereby may reach a consensus about a trans-scientific issue, or the discovery of some appropriate adaptive behavior to the outer environment through active interactions for resolving a trans-scientific matter, such as the question: “To what extent are self-actions for continuous improvement of

\(^{21}\)See The President’s Commission,\(^{(23)}\) pp. 63–64.

\(^{22}\)See Simon,\(^{(36)}\) p. 25.

\(^{23}\)See Weinberg,\(^{(12)}\) p. 222.
safety to be taken in managing a severe accident?" for instance.

3.4.2. Possible Means for Procedural Rationality

Herbert Simon is an exceptionally renowned scientist who received the Turing Prize in computer sciences as well as the Nobel Prize in economic sciences. He developed an idea of using artificial intelligence, which is useful for discovering appropriate adaptive behavior, i.e., procedural rationality.

In referring to Simon’s idea, a self-organizational cross-checking system using computerized knowledge management tools for reducing the occurrence of human errors and a data recording and storing system for minimization of falsification, mentioned earlier, are to be interpreted as a means for a kind of procedural rationality. The systems are useful for alleviating the possible suspicion arising from information asymmetry between the inner environment (company) and the outer environment (public). However, they are designed not to be directly but to be indirectly interactive with the outer environment.

A more straightforward approach on an active interaction is to stimulate self-actions for continuous improvement in safety based on the INPO rating of an individual plant’s safety performance and on a performance-based regulatory system, for example. In particular, the INPO rating system is truly suitable for such an approach because the rating results are institutionally reflected in determining the amount of insurance charges by Nuclear Electric Insurers Ltd., which was established to shield individual nuclear utilities against the cost of replacement energy when a plant is shut down by an accident, thereby avoiding a repeat of the crippling financial burdens experienced by TMI’s parent company.24

The system has been introduced effectively in the United States. In Japan, it is as yet only under consideration or out of scope. The reason for insufficiency of consciousness on the need for such an approach is that the Japanese people are not fully aware of the recent advances in scientific ideas in the area of trans-scientific issues. It is hoped that once the people recognize the usefulness of those ideas, an innovative change in managing the nuclear safety issues facing them will occur.

4. CONCLUDING REMARKS—MANAGING THE INEVITABILITY OF THE ACCIDENT

Looking back at the history of nuclear reactor accidents and incidents, it appears that serious or near-serious accidents/incidents have happened at least once a decade, and the causes have been repeatedly observed.25 Because of the repetitive nature of the causes of these accidents, people worry about the inevitability of serious accidents.

With respect to the Fukushima Daiichi accident, Charles Perrow25 specifically warned of such an inevitability, referring to the following features:

(1) regulatory incompetence and capture;
(2) regarding warnings of looming disasters as mere obstructionism;
(3) many nonlinear system properties of a complex organization; and
(4) prosaic organizational failures always being with us and knowledge always being incomplete or in dispute.

As described earlier in this article, these features are associated with information asymmetry and hit a centrally crucial point about the causes of the Fukushima Daiichi accident and, no doubt, lessons learned would be of little use without well-thought-out action plans for managing the features. This article has been aimed at helping establish the plans to manage this inevitability.

How the nuclear industry has behaved every time it was faced with a major accident has been more or less the same, implementing the following two measures separately: (1) technical or scientific adaptation for safety enhancement, including, in most cases, strengthening regulations; and (2) reconsidering social or institutional arrangements with an emphasis on so-called safety culture.

24 See Rees, (25) pp. 93–94.

25 For example, (1) Windscale (1957, United Kingdom), severe accident due to technological immaturity, (2) Three Mile Island (1979, USA), severe accident due to human error and improper man-machine interface, (3) Chernobyl (1986, USSR), severe accident due to insufficient safety culture of organization, (4) Le Blayais (1999, France), serious incident due to beyond design basis flooding, (5) Davis Besse (2002, USA), serious incident due to new scientific findings and deceit of indicators, (6) Forsmark (2006, Sweden), near-serious incident due to insufficient safety culture, (7) Kashiwazaki-Kariwa (2007, Japan), near-serious incident due to beyond design basis earthquake, (8) Fukushima Daiichi (2011, Japan), severe accident due to beyond design basis tsunami and new scientific findings.
The author, however, does not think the approach we have used so far is good enough to avoid a repetition. With the enormously human-behavior–linked and sophisticated nature of the nuclear accidents in mind, we should look for an innovative way to assure that countermeasures are taken not separately but interrelatly.

In other words, social or institutional arrangements are necessary to strengthen self-efforts for continuous improvement of safety, which tend to be weakened due to the so-called information asymmetry. To overcome the problem, arrangements are to be made specifically dedicated to pursuing procedural rationality, in which a communicative action with transparency and a self-regulating system are particularly useful.

This is the challenge facing the global nuclear future to be tackled in the wake of the Fukushima Daiichi accident.

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