Why You Haven't Heard About Onagawa Nuclear Power Station after the Earthquake and Tsunami of March 11, 2011

Nuclear Safety Culture in TEPCO and Tohoku Electric Power Company: The root-cause of the different fates of Fukushima Daiichi Nuclear Power Plant and Onagawa Nuclear Power Station

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> "THE EARTHQUAKE AND TSUNAMI of March 11, 2011 were natural disasters of a magnitude that shocked the entire world. Although triggered by these cataclysmic events, the subsequent accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. It was a profoundly manmade disaster – that could and should have been foreseen and prevented…
>
> This was a disaster "Made in Japan"…
>
> Japan's nuclear industry managed to avoid absorbing the critical lessons learned from Three Mile Island and Chernobyl…
>
> It was this mindset that led to the disaster at the Fukushima Daiichi Nuclear Plant.
>
> The consequences of negligence at Fukushima stand out as catastrophic, but the mindset that supported it can be found across Japan."

[Dr. Kiyoshi Kurokawa's "Message from the Chairman", *The Official Report of the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission* (NAIIC, July 2012).]

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Introduction

On March 11th 2011 2:46pm, the biggest recorded earthquake in Japanese history with the focal area extending 500km in length and 200km in width hit Tohoku prefecture, leaving over 20,000 people dead or missing. The destructive 9.0 magnitude earthquake was followed by a tsunami of magnitude 9.1 that travelled a maximum of 10km inland with waters reaching a run up height of 43.3 meters in some areas, sweeping entire towns away in seconds. Within the affected area existed two nuclear power plants run by two companies - the Onagawa Nuclear Power Station (hereby Onagawa NPS) operated by Tohoku Electric Power Company and Fukushima Daiichi Nuclear Power Plant (hereby Fukushima Daiichi NPS) operated by Tokyo Electric Power Company (TEPCO). While the two power stations experienced similar aftermaths of the disaster and operated under the same regulatory regime, their fates were undeniably contrasted. When Fukushima Daiichi NPS experienced a fatal meltdown, Onagawa NPS managed to remain generally unwounded.

In fact according to an IAEA mission who visited Onagawa NPS and evaluated the performance of its systems, structures and components following the earthquake and tsunami, the plant, which was "the closest nuclear power station to the epicenter of the enormous M9.0 GEJE…(and) due to is proximity to the earthquake source, the plant experienced very high level of ground motion – the strongest shaking that any nuclear plant has ever experienced from an earthquake," however it "shut down safely" was "remarkably undamaged" ((IAEA, 2012, p.6).

The purpose of this article is to shed light on why the Onagawa NPS, which experienced "the strongest shaking that any nuclear plant has ever experienced from an earthquake" as well as the higher tsunami wave height than Fukushima Daiich nuclear power plant, had a different fate from Daiichi and was able to shut down safely.

Fukushima Daiichi NPS and the meltdown

Fukushima Daiichi Nuclear Power Plant is located in the Tohoku region of Japan, and consists of six total nuclear reactors all facing the Pacific Ocean. The first nuclear reactor, contracted with GE operated by TEPCO, was built to completion in September 1967 and began operating on March 1971. All six reactors are type BWR (boiling water reactor), and the basic setup of such reactors can be seen in the diagram below given by TEPCO.

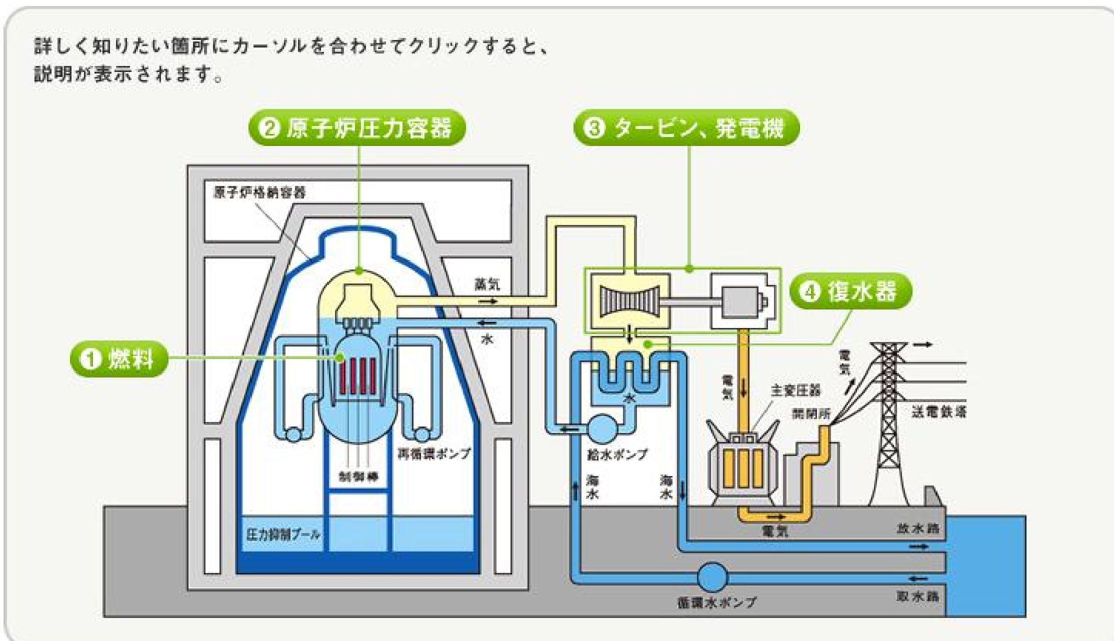

Figure 1. TEPCO nuclear reactor setup diagram (TEPCO, 2013)

The Reactor Pressure Vessel (RPV) labeled ②原子炉圧力容器 is located inside the Primary Containment Vessel (PCV). RPV contains the reactor core which contains nuclear fuel ①燃料 in the form of fuel rods, which are sunk under water. Pipes that bring water into the RPV and send steam out are connected to the water tank and turbine ③タービン, respectively. The high temperature/pressure steam that comes out of the RPV will turn the turbine, allowing electricity to be generated at the power generator ③発電機. The high temperature/pressure steam is cooled down using a condenser ④復水器 that flows cold sea water through a pipe so the internal water can recirculate into the RPV again. This design is a BWR Mark 1 nuclear reactor designed in the early 1960s – the same design implemented at the Onagawa Nuclear Power Plant.

When coolants are lost, an emergency core cooling system (ECCS) is activated for all six nuclear reactors. The high power coolant injection system included in reactors 1,2, and 3 uses DC battery power to draw out water from the containment suppression chamber located at the bottom of the reactor. Electrically operated low-pressure coolant injection systems that add additional back up also exist. As with ECCS and other emergency systems implemented that are not mentioned, DC/AC battery power, back-up generators, and diesel generators are required to power these systems.

At 2:46pm when the 9.0 magnitude earthquake hit, Unit 1, 2, and 3 were shut down automatically. Units 4, 5, and 6 were not operating at the moment of impact. The shock of the earthquake resulted in the loss of all external power supplies, causing the emergency diesel generators to operate, heating up the inside of the reactors. Fission reactions continued even after shut down in Units 1, 2, and 3. Due to the inability to remove residual heat because of the loss of external power supplies increased reactor pressure, pervading steam throughout the reactor. The tsunami hit 41 minutes after the earthquake, sending a 13.1m high wave towards the reactors, drowning cooling circuits, Residual Heat Removal (RHR) cooling systems, and electrical batteries, inevitably isolating the reactors.

Onagawa NPS and the impact from the earthquake

Similar to Fukushima Daiichi NPS, Onagawa NPS reactors are BWR Mark 1 type reactors. However, unlike Fukushima Daiichi NPS, Onagawa NPS only has three reactors in total with the first reactor operating on June 1st 1984. The biggest difference between the two reactors is that during construction, Tohoku Electric placed the reactor components (such as RPV, fuel rods, turbines) secondary to the location and orientation of the reactor building. In other words, the reactor building was prioritized to be in a safe area, and the internal components were organized and placed accordingly. The diagram of reactor 1 at Onagawa NPS below shows the detailed attention paid to the design of the building.

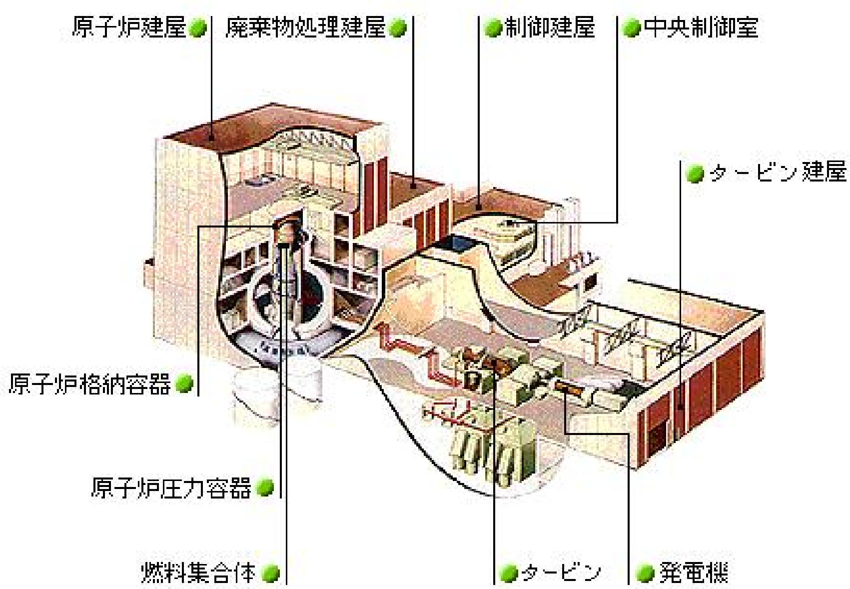

Figure 2. Onagawa Plant Reactor 1 set up (Tohoku Electric Power Company, 2013)

Onagawa NPS's reactors all have a Reactor Core Isolation Cooling System (RCIC), Residual Heat Removal System (RHR), and Emergency Core Cooling System (ECCS). It has five off-site power source circuits that support the operations of the reactors.

While the majority of the two power plants were functionally very similar, the two differed undeniably in their facility design. The most evident difference, which presumably saved Onagawa NPS from a meltdown, was the elevation of the reactors. With historical data noting tsunamis in Tohoku to average

3 meters prior to nuclear reactor construction, Tohoku Electric constructed their plant at 14.7 meters high, approximately 5 times the height of the expected tsunami. Tepco, on the hand, to make it easier to transport equipment and to save construction costs, in 1967 removed 25 meters off the 35-meter natural seawall http://online.wsj.com/news/articles/SB10001424052702303982504576425312941820794 of the Daiichi plant site and built the reactor buildings at a much lower elevation of 10 meters (*The Wall Street Journal*, July 12, 2011). According to the National Diet of Japan's Fukushima Nuclear Accident Independent Investigation Commission (NAIIC), the initial construction was based on existing seismological information, but later research showed that tsunami levels had been underestimated. While Tohoku Electric learned from past earthquakes and tsunamis—including one in Chile on February 28, 2010—and continuously improved its countermeasures, Tepco overlooked these warnings. According to the NAIIC report, Tepco "resorted to delaying tactics, such as presenting alternative scientific studies and lobbying."

Tepco's tsunami risk characterization and assessment was, in the judgment of http://www.nytimes.com/2011/03/27/world/asia/27nuke.html?pagewanted=all&_r=0 of one the world's renowned tsunami experts, Costas Synolakis, director of the Tsunami Research Center http://www.usc.edu/dept/tsunamis/2005/index.php at the University of Southern California, a "cascade of stupid errors that led to the disaster." [*The New York Times*, March 26, 2011.]

Due to such safety precautions, although the earthquake initially caused four out of 5 of Onagawa NPS's off-site power source circuits to fail, 60% of these circuits were recovered within a day, and all circuits were operating by the end of the month. During the loss of the four circuits, power was distributed throughout all the units using a startup transformer. When the startup transformer became unavailable, the emergency diesel generators were used as a power source. At Unit 1, a high-voltage power distribution panel fire occurred inside the turbine building, but the fire was successfully extinguished 7 hours later.

In order to counteract the effect of the disaster, Tohoku Electric Power Company established an Emergency Response Center at Onagawa NPS as well as at the headquarters immediately after the earthquake. Throughout the disaster, headquarters supported the operators at Onagawa NPS minute by minute. Supervisors, as well as chief engineers were sent to the main control rooms of the damaged nuclear reactors to make good emergency decisions. Information was sent accurately and in a timely manner to all levels of operations in order for the company to work collectively to resolve the situation.

Root-cause of Fukushima Daiichi NPS and Onagawa NPS's different fates

Today, the general public believes the meltdown at Fukushima Daiichi NPS was predominantly due to the earthquake and tsunami. Knowing the outcome of Onagawa NPS, we cannot say this is true for several reasons.

1. Onagawa NPS was closer to the epicenter than Fukushima Daiichi NPS

When comparing the direct distance between the epicenter and the two nuclear power stations, Onagawa NPS was 123km away from the epicenter, 60km closer to the epicenter than Fukushima Daiichi NPS, which was 183km away from the epicenter. Since intensities of the earthquake, as well as the tsunami increases as the distance to the epicenter decreases, the Onagawa NPS should have been impacted more severely.

2. The tsunami measured at Onagawa NPS was higher than at Fukushima Daiichi NPS

According to Japan Meteorological Agency (2011), the tsunami reached a height of 14.3 meters at Onagawa NPS whereas it was 13.1 meters at Fukushima Daiichi NPS. While the tsunami was higher at Onagawa NPS, it did not suffer the same consequences as Fukushima Daiichi NPS did. According to Nippon Telegraph and Telephone Facilities Research Institute in Japan, TEPCO, the operators of Fukushima Daiichi NPS, claims that the loss of the emergency diesel generator, as well as the backup generators and cooling system were due to the tsunami and the unexpected height. However, the tsunami cannot be fully blamed for the breakdown of the nuclear reactors if Onagawa NPS experienced a higher tsunami and managed to survive.

3. The earthquake seismic intensity at the two nuclear power plants were negligibly different

Compared to the upper 6 seismic scale (震度) earthquake that hit Fukushima Daiichi NPS, the earthquake that hit Onagawa NPS was lower 6 seismic scale, a relatively negligible difference in intensity. This difference is too small to be able to explain the entirety of the loss of the AC power supplies.

Such insignificant differences in the conditions the two Nuclear Power Plants faced imply the root-cause lies somewhere besides the earthquake and tsunami. By comparing the decision making process of TEPCO and Tohoku Electric Power Company during the disaster, it is evident that Tohoku Electric Power Company's response was more organized, collaborative, and controlled compared to TEPCO. Tohoku Electric Power Company's strong ability to remain poised and unified as a team during unexpected situations allowed them to avoid a catastrophic incident. Thus, the earthquake and tsunami was in fact only a trigger to a meltdown that was caused by improper decision making by TEPCO and operators of Fukushima Daiichi NPS.

But why was Tohoku Electric Power Company more able in emergency situations in comparison to TEPCO? According to Nippon Telegraph and Telephone Facilities Research Institute (Ogata, December 2012), Yanosuke Hirai, the Vice President of Tohoku Electric Power Company from 1960 to 1975, was very adamant about safety protocols, and continued to insist on prioritization of safety regardless of constant disagreement. He personally became a member of "Coastal Institution Research Association (海岸施設研究委員会)" in 1963 in order to further appeal the importance of protection against natural disasters. Mr. Ogawa, a project participant of Onagawa NPS states, "If you do not think about tsunamis in Tohoku, what are you thinking? That was the mentality within Tohoku Electric Power Company." (Ogata, December 2012) By having an employee in upper management strongly advocating safety, a general prioritization for nuclear reactor safety formed within the company. Prior to reactor construction, Tohoku Electric Power Company as a whole conducted bibliographic, inquiry, archaeological, and sediment-related surveys, as well as literary research on historical natural disasters in Tohoku to determine potential tsunami height. In addition, numerical calculations and simulations based on basic earthquake models, as well as tsunami models were used to estimate the maximum and minimum water level. Out of work hours, representatives of Tohoku Electric Power Company participated in seminars and panel discussions about earthquake and tsunami disaster prevention in nuclear energy held by Japan Nuclear Energy Safety Organization, where representatives were exposed to further information and prevention techniques in the nuclear department.

However, it is not only the upper management's understanding of the importance of safety that impacted Onagawa NPS to be better prepared for disasters. By implementing strict protocols for when a disaster occurs, all workers were familiar with the steps that must be taken when either a tsunami warning was issued, or when a tsunami was approaching. Periodic training sessions to remind workers of extreme situations also allowed employees to stay poised during an actual disaster.

Such initiatives seen in Tohoku Electric company culture to prioritize citizen safety cannot be found in TEPCO culture. Unlike Tohoku Electric Power Company, because of TEPCO's monopoly in the electricity industry, within the company exists a mindset that their domination in the market is an indication of flawlessness.

Hasuike Tooru, the former president of TEPCO, describes his view of management's economic goal and their profit-centered behavior.

"With the general lifetime of a nuclear reactor as approximately 40 years, most of the nuclear reactors at Fukushima Daiichi Nuclear Power Plant were reaching the end of their life. However, management had been discussing the benefits of keeping the reactors running and earning extra profit from the depreciated reactors. The incentives that ran such discussion were in hopes of generating easier returns with simpler operations. (Nikkan SPA!, 2011)*" - Haisuke Tooru (Translated by author)*

As a result, the management decided to lengthen the expected lifetime of the power plants, even if there were severe safety consequences linked to it. This mentality of gaining profit the easiest way possible, is a mindset that was not found in Tohoku Electric Power Company. It is evident that safety protocol was neglected when making decisions, and because TEPCO were monopolizing the market, most people had the cavalier mentality that "nothing will go wrong", thus spent little time considering safety.

This lack of time spent addressing safety can be seen in TEPCO's company culture during the construction stage of Fukushima Daiichi NPS. According to the National Diet of Japan Fukushima Accident Independent Investigation Commission (NAIIC), the initial construction of Fukushima Daiichi NPS was based on seismological information, resulting in building Fukushima Daiichi NPS at a terrain of 10m. As further research was conducted, professional researchers found the safety foundations the nuclear reactors were built on underestimated tsunami levels. Regardless, TEPCO disregarded such warnings as minor differences. Besides this warning of inaccurate tsunami level estimations, three other issues regarding the methodology, interpretation, and selection in evaluating tsunami levels were found by Nuclear and Industrial Safety Agency (NISA). NAIIC claims:

"As the regulatory agency, NISA was aware of TEPCO's delaying of countermeasures, but did not follow up with any specific instructions or demands. Nor did they properly supervise the backcheck progress. (Kurokawa et. al, 2012)*"- NAIIC*

However, Tohoku Electric Power Company, whose regulatory agency is also NISA, did not have similar risk management issues as TEPCO did. According to a presentation on Onagawa NPS done at The National Academies by Akiyoshi Obonai and Takao Watanabe of Tohoku Electric Power Company on November 2012, Tohoku Electric Power Company was able to successfully predict future tsunami levels by conducting numerical simulations as well as multiple surveys. As a result of their surveys, the estimated tsunami level was initially predicted to be 3m in 1970. As more research was done through numerical simulations and field studies, the new estimated tsunami level in 1987 went up to 9.1m (Obonai, 2012), and 13.6 (Obonai, 2012) in 2002. Such periodic checkups of tsunami conditions and possible changes in tsunami levels show good risk management within the Tohoku Electric Power Company. If Tohoku Electric Power Company was able to predict tsunami levels accurately while being under the same regulatory system as TEPCO, it is certain that the blame is not entirely on NISA. Thus, the fault is in TEPCO's risk management plan, or rather a lack of.

Safety Culture and its Role in the Fukushima Accident

The vital and pervasive role of safety culture in Fukushima accident have explicitly been acknowledged by governmental investigations such as the *Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety: The Accident at TEPCO's Fukushima Nuclear Power Stations* (June 2011); and the report of National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission

(NAIIC, July 2012). The following relevant excerpts from these two authoritative reports are noteworthy in this context:

> "[Lessons in Category 5:] Thoroughly instill a safety culture, raise awareness of safety culture… All those involved with nuclear energy should be equipped with a safety culture… Learning this message and putting it into practice is the starting point, duty and responsibility of those who are involved with nuclear energy. *Without a safety culture, there will be no constant improvement of nuclear safety".* (pages XII-13-14, emphasis added)

According to the NAIIC chairman, Dr. Kiyoshi Kurokawa's "Message From the Chairman":

> "Accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. *It was a profoundly manmade disaster – that could and should have been foreseen and prevented*… This was a disaster "Made in Japan… Japan's nuclear industry managed to avoid absorbing the critical lessons learned from Three Mile Island and Chernobyl… It was this mindset that led to the disaster at the Fukushima Daiichi Nuclear Plant." (Emphasis added)

Chairman of the US Nuclear Regulatory Commission (NRC), Dr. Allison M. Macfarlane, echoed the same sentiment and further emphasized the importance of safety culture in her remarks before the International Nuclear Safety Group (INSAG) Forum of the International Atomic Energy Agency (IAEA) on Monday, September 17, 2012, in Vienna, Austria:

> "There are many lessons that we must all take away from the accident at Fukushima, but some of the most valuable *extend beyond* the

> technical aspects and are embedded in human and organizational behaviors. Among these is *safety culture*." (Emphasis added)

Safety Culture and Past Nuclear Accidents – Exhibit A: Chernobyl

It is believed that it has been the accident at the Chernobyl nuclear power plant which formally introduced the concept of 'safety culture' to the vocabulary of nuclear safety. According to the International Atomic Energy Agency (IAEA), "the term 'safety culture' came into use after the Chernobyl accident" (*Nuclear Safety Review 1992*, p. D24). Safety culture, nowadays, has also been embraced by other industries, such as chemical processing, refining, commercial aviation, and health care.

According to the IAEA, "the (Chernobyl) accident can be said to have flowed from deficient safety culture, not only at the Chernobyl plant, but throughout the Soviet design, operating, and regulatory organizations for nuclear power that existed at the time....Safety culture ... requires total dedication, which at nuclear power plants is primarily generated by the attitudes of managers of organizations involved in their development and operation" (IAEA, 1992, p.24).

Safety culture definition (characteristics, pillars and constituting elements)

Complex technological systems, such as nuclear power plants are subject to risks of natural hazards phenomena and man-made actions. A characteristic common to these technological systems is the large amount of potentially hazardous materials concentrated in single sites under the centralized control of a few human operators. Potential catastrophic breakdowns of these systems, often characterized as 'low probability, high consequence', pose serious threats for workers in the plant, the local public, and possibly the neighboring region and parts of the whole country. In the foreseeable future, despite increasing levels of computerization and automation, human operators and organizations will remain in charge of the day-to-day controlling and monitoring of these systems. Thus, the safe and efficient operation of these technological systems is a function of the interactions among their Human, Organizational, and Technological (i.e., engineered) (HOT) subsystems, within their overall operational milieu -- *safety culture* (Meshkati, 1995).

The connection of these three (HOT) subsystems, in the context of the total system, is represented in Figure 1. This simplified and symbolic demonstration depicts only one critical system's reality -- the role of each subsystem as a link in a chain -- in the integrity of the whole system. It does not, however, show all the needed subsystems' interactions and interrelationships.

The chain metaphor is also helpful in understanding the effects of output or production load, produced by the system, on its individual subsystems. Any increase in the output level or the capacity utilization rate imposes strain on <u>all</u> subsystems.

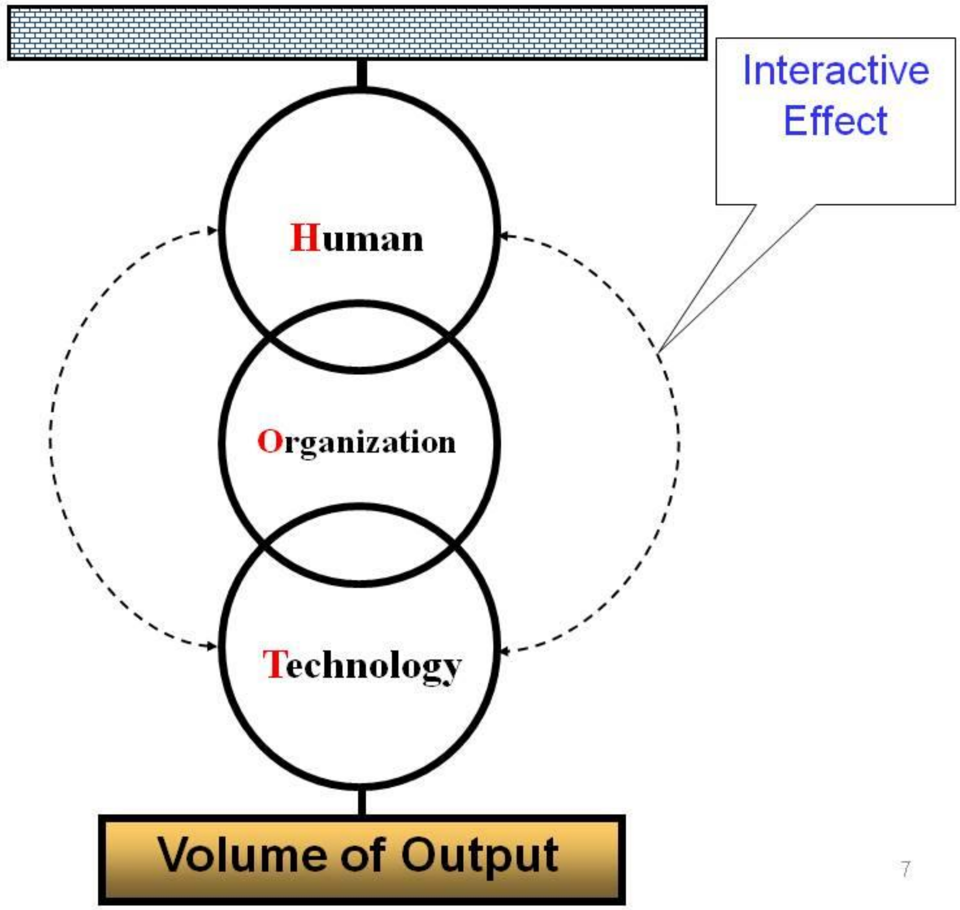

Figure 1: Major Subsystems of a Technological System

Obviously, the chain (system) could break down if any link breaks down. This may occur if either all the links (subsystems) are not *equally* strong and designed for handling the additional load, or if they are not *adequately* prepared and reinforced to carry the extra load in a sustainable fashion. Major accidents at complex, large-scale technological systems have been caused by break downs of the weakest links in this chain, which are most often the human or organizational subsystems.

Finally, Safety culture can also be characterized as the "overlay" or direct result of sound HOT interactions that should have been incorporated during work system's design and nurtured and maintained during operation stages. Furthermore, an organization's safety culture, as a *system* composed of behaviors, practices, policies, and structural components, cannot flourish or succeed without interactions and harmony with its *environment* -- the societal or national culture in which the organization which runs the technological system must operate. In other words, safety culture should be considered in the context of national culture, which could seriously affect its effectiveness (Meshkati, 1999; Gelfand, Frese, and Salmon, 2011).

Creating and nurturing a positive safety culture basically means to instill thinking and attitudes in organizations and individual employees that ensure safety issues are treated as high priorities. An organization fostering a safety culture would encourage employees to cultivate a questioning attitude and a rigorous and prudent approach to all aspects of their job, and would set up necessary open communications between line workers and mid- and upper management. These safety culture characteristics are equally applicable both to the operating companies as well as to their cognizant/designated governmental regulatory safety agency.

<u>US and Global Nuclear Power Industry and Safety Culture</u>

The recently published Nuclear Regulatory Commission's (NRC) Final Safety Culture Policy Statement (*Federal Register*, 2011) which is the final outcome of many years of joint industry-regulator efforts, defined safety culture as ""*The core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment*." According to this document, the nine "traits of positive safety culture" include:

1. **Leadership Safety Values and Actions** - Leaders demonstrate a commitment to safety in their decisions and behaviors;

2. **Problem Identification and Resolution** - Issues potentially impacting safety are promptly identified, fully evaluated, and promptly addressed and corrected commensurate with their significance;
3. **Personal Accountability** - All individuals take personal responsibility for safety;
4. **Work Processe**s - The process of planning and controlling work activities is implemented so that safety is maintained;
5. **Continuous Learning** - Opportunities to learn about ways to ensure safety are sought out and implemented;
6. **Environment for Raising Concerns** - A safety conscious work environment is maintained where personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment, or discrimination;
7. **Effective Safety Communication** - Communications maintain a focus on safety;
8. **Respectful Work Environment** - Trust and respect permeate the organization; and
9. **Questioning Attitude** - Individuals avoid complacency and continuously challenge existing conditions and activities in order to identify discrepancies that might result in error or inappropriate.

The US nuclear power industry, under the leadership of the Institute of Nuclear Power Operations (INPO) and Nuclear Energy Institute (NEI) have produced extensive studies and guidelines on safety culture, which include *Fostering a Strong Nuclear Safety Culture* [by the Nuclear Energy Institute (NEI), 09-07, June 2009].

INPO has been very active in its safety culture efforts. Most recently it has released its seminal study, *Traits of a Healthy Nuclear Safety Culture* (April 2013) that builds on the knowledge and experience it gained since the publication of its *Principles of a Strong Nuclear Safety Culture* in 2004. INPO defines safety culture as:

> Nuclear safety culture is defined as the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment.

According to INPO, "*Traits of a Healthy Nuclear Safety Culture* reflects an alignment in two sets of terms that have been used to describe nuclear safety culture: INPO and the industry defined safety culture in leadership terms of principles and attributes, and the U.S. Nuclear Regulatory Commission defined safety culture in regulatory terms of components and aspects. Whereas each set of terms served its special function, the result created confusion within operating organizations as to the essential elements of a healthy safety culture." INPO contends that, "*Traits of a Healthy Nuclear Safety Culture* describes the essential traits and attributes of a healthy nuclear safety culture, with the goal of creating a framework for open discussion and continuing evolution of safety culture throughout the commercial nuclear energy industry."

In addition to above document, INPO has produced two addendums. *Addendum I: Behaviors and Actions That Support a Healthy Nuclear Safety Culture by Organizational Level* (April 2013) describes nuclear safety behaviors and actions that contribute to a healthy nuclear safety culture by organizational level—executive/senior manager, manager, supervisor, and individual contributor, and *Addendum II: Cross-References* (April 2013) provides cross-references from *Traits of a Healthy Nuclear Safety Culture* to the safety culture guidance developed by the Department of Energy (DOE) and the Energy Facility Contractors Group (EFCOG).

The US Department of Energy (DoE) has recently produced several major guidelines and handbooks which extensively address safety culture and its hurdles and implementation. They include *Accident and Operational Safety Analysis, Volume I:*

Accident Analysis Techniques (2012); *Human Performance Improvement Handbook, Volume 1: Concepts and Principles* (2009); and *Human Performance Improvement Handbook, Volume 2: Human Performance Tools for Individual, Work Teams, and Management* (2009).

[The above-mentioned DoE (2012) includes a useful guide to help identify latent organizational weaknesses - those factors in the management control processes or associated values that influence errors or degrade defenses. It enables the user to consider work practices, resources, documentation, housekeeping, industrial safety, management effectiveness, material availability, oversight, program controls, radiation employee practices, security work practices, tools and equipment use, training and qualification, work planning and execution, and work scheduling. Moreover, this Handbook includes an expanded list of such examples in its Attachment 1, *ISM (Integrated Safety Management) Crosswalk and Safety Culture Lines of Inquiry,* to further indentify safety culture-related issues.]

In *Safety Culture*, a report by the International Nuclear Safety Advisory Group of the IAEA, safety culture is defined as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance" (IAEA, 1991, p. 4).

In summary, according to the IAEA, safety culture is defined as the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, safety issues receive the attention warranted by their significance. Two general components of the safety culture are the necessary framework within an organization (whose development and maintenance is the responsibility of top management) and the attitude of staff at all different levels in responding to and benefiting from the framework. The requirements of individual employees for achieving safety culture at technological companies are a questioning attitude, a rigorous and prudent approach, and necessary communication.

IAEA's safety culture series, which were produced subsequent to the aforementioned reports on the Chernobyl accident, including its latest reports, *Safety Culture in Nuclear Installations: Guidance for use in the Enhancement of Safety Culture* (2002); *Safety Culture in the Maintenance of Nuclear Power Plants* (2005); and its most recent one *Safety Culture in Pre-Operational Phases of Nuclear Power Projects* (2012) are further acknowledgments of and testaments to the vital importance of safety culture in safe and accident-free life-cycle of nuclear power plants around the world.

According to a recent major series of studies by the Swedish Radiation Safety Authority, such as *A Guidebook for Evaluating Organizations in the Nuclear Industry: An Example of Safety Culture Evaluation* [2011 (Report number: 2011:20 ISSN: 2000-0456)], an organization has good potential for safety when it has developed a culture that shows willingness and an ability to understand risks and manage the activities so that safety is taken into account. The following criteria are to be met in the organizational activity to achieve a strong safety culture:

1. Safety is a genuine value in the organization and that is reflected in the decision-making and daily activities;
2. Safety is understood to be a complex and systemic phenomenon;
3. Hazards and core task requirements are thoroughly understood;
4. The organization is mindful in its practices;
5. Responsibility is taken for the safe functioning of the whole system; and
6. Activities are organized in a manageable way.

Other Industries, trade and professional associations have also addressed safety culture. Such noteworthy reports include; *Building Process Safety Culture: Tools to Enhance Process Safety Performance* [by the Center for Chemical Process Safety (CCSP) of the American Institute of Chemical Engineers (AIChE), 2005]

Healthy Nuclear Safety Culture Traits by INPO

These two polar opposite company cultures represent the how large of an influence human factors and working environment has on company decisions and actions. To further understand these two cultures, the Healthy Nuclear Safety Culture Traits developed by INPO (2013) were used and compared. Below is a company-based comparison of the INPO traits.

INPO Traits	Tohoku Electric	TEPCO
Personal Accountability	○	X
Leadership Safety Values and Actions	○	X
Effective Safety Communication	○	△
Respectful Work Environment	○	○
Environment for Raising Concerns	X	X
Decision-Making	○	X
Work Processes	○	○
Questioning Attitude	△	X
Continuous Learning	○	○
Problem Identification and Resolution	△	△

Table 3. INPO Trait Comparison for Tohoku Electric and TEPCO (INPO, 2013)

*○ refers to yes, has the trait, and ҇7 refers to no, does not have the trait, △ represents the medium of ○ and **X**. The results above are subject to the author's personal interpretations and assumptions

Personal Accountability refers to individuals taking personal responsibility for safety. The vice president of Tohoku Electric Power Company at the time of construction once said, "I respect the law. But for technicians and engineers, regardless of what the law says, the responsibility of failure is always on us (Ogata, December 2012)". Hirai, the vice president, understood that safety failures would be the personal responsibility of him and his company. On the other hand, TEPCO did not even believe failure could occur, and consequently did not feel personally accountable for safety failures.

Leadership safety values and actions were clearly present at Tohoku Electric Power Company, for Mr. Hirai was very adamant on implementing the highest safety for the Onagawa NPS. On the contrary, as Mr. Hasuike, prior president of TEPCO noted, upper management prioritized profitability and ease of operation over safety.

Environment of raising concerns is a trait that is very difficult to achieve in Japan. The reserved culture and personality of Japanese people make it challenging for most people to outwardly express their concerns to others. Therefore, even if there is an effort in the company to strive for an environment where concerns can be raised, the innate characteristics of Japanese people make it hard to implement.

Decision-making refers to the ability to understand expectations, and act accordingly and lead the reactor to a safe condition under unexpected conditions. As seen clearly in the aftermath of the Tohoku Earthquake and Tsunami Disaster, Tohoku Electric was able to execute emergency protocol well, while TEPCO was not able to react to unexpected conditions.

Questioning attitude refers to the ability of individuals to challenge existing conditions or ideas to identify possible errors. This without a doubt did not exist in TEPCO. This lack of questioning attitude is in fact very prominent in most companies in Japan. Because of the nation specific culture of submissiveness and conservativeness, most people do not tend to challenge other people's ideas or opinions because it is considered rude and disrespectful. The general company culture in Tohoku Electric also represents a typical Japanese firm with little questioning attitude. Regardless, Tohoku Electric received △ because of Mr. Hirai's exceptionally forward behavior in pushing for higher safety protocol.

Overall, TEPCO does not achieve even half of the traits assumed to be important in a healthy nuclear safety company. Tohoku Electric on the other hand, is able to achieve most of these traits by having a constant vision towards a safe nuclear environment and company ethics that try to improve citizen lives.

Conclusion

On the surface, the Fukushima Daiichi NPS meltdown may have seemed like it was caused by the earthquake and tsunami. However, with Onagawa NPS in an almost identical situation but escaped a meltdown, it is inevitable to realize the existence of a different cause. As Dr. Kiyoshi Kurokawa, Chairman of the National Diet of Japan's Fukushima Nuclear Accident Independent Investigation Commission states, the root cause of the Fukushima Daiichi NPS meltdown was ultimately the "mindset" of TEPCO. The meltdown was not due to the natural disaster, but was a result of consecutive decisions neglecting safety, rooting back to when the reactors were being constructed. If safety and disaster response was properly recognized, addressed, and implemented like it was in Tohoku Electric Power Company's culture, perhaps the Fukushima Daiichi NPS meltdowns could have been prevented.

The decisions that nuclear plant managers, utility company executives, and government officials make now will have a major impact on nuclear power safety and may result in possible consequences in Japan, as well as the world. As a new seminal investigative book on Fukushima concluded: "Other methods of generating energy also carry risks, in terms of environmental costs as well as human health and safety impacts. But that is no excuse for continuing to hold nuclear power only to the inadequate safety standards that made the Fukushima disaster possible. Nuclear technology is an unforgiving technology and the consequences of a mistake can be catastrophic" [*Fukushima: The Story of a Nuclear Disaster*, by David Lochbaum, Edwin Lyman, and Susan Q. Stranahan, Union of Concerned Scientists, 2014.]. We have experienced this, once, on March 11, 2011. It may be worthwhile to revisit nationwide nuclear safety standards before moving forward with the New Basic Energy Plan in Japan.

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