Lessons Learned from the Fukushima Daiichi Nuclear Accident – A Discussion from a Neutral Point of View – 14384

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ABSTRACT

Although the nuclear industry, as well as the world, was shaken by the accident in 2011 at the Fukushima Daiichi nuclear power plant, it was predicted that, even after this accident, a 60% increase in nuclear energy worldwide would be needed by 2035, due to increasing demands for energy, an awareness of global warming, the security of energy supplies, and many other social and economic factors.

Even a nuclear reactor designed, constructed and managed based on the best available technologies for safety at the time would be vulnerable to a nuclear accident and/or enhanced impact from such an accident. Various technical, cultural and social factors may be involved, including design criteria; quality control in manufacturing and construction; system decay over time; human error in operating and maintaining the reactor; natural hazards such as earthquakes, extreme weather conditions, tsunamis, and floods; and terrorism.

This presentation shows a brief overview of the Fukushima Daiichi nuclear accident, together with major progress and the remaining challenges associated with nuclear disasters. The lessons learned from this accident suggest an ideal framework for preventing and/or minimizing the effects of disasters potentially induced by a nuclear accident. Although not perfect, due to the complexity of the topic, ideal considerations of organizational and regulatory systems; crisis management, emergency response, public communication systems; knowledge and education about risks of exposure to radiation, and effective decontamination of radioactive substances are discussed and summarized.

INTRODUCTION

On March 11, 2011, a massive earthquake of magnitude 9.0 on the Richter scale struck the northeast coastal region of Japan. An unprecedented, giant tsunami following this massive earthquake led to the loss of thousands of lives, and damaged the Fukushima Daiichi nuclear power plant, due to the prolonged loss of electric power supply and the ultimate heat sink required for cooling [1]. Although the nuclear accident did not cause any casualties directly, the daily lives of thousands of people living in the Tohoku region, especially those displaced from their hometowns, have been severely affected. This region experienced a huge economic loss, along with the contamination of a large area by radioactive substances. Although more than two and a half years have passed since the accident, Japan has experienced many difficulties recovering. Considerable time is needed before decommission on-site, decontamination off-site and reconstruction in the Tohoku region can be completed [2, 3].

Although the nuclear industry, as well as the world, was shaken by the Fukushima Daiichi nuclear accident, it was estimated that a 60% worldwide increase in nuclear energy would be necessary by 2035 due to increasing demands for energy, the awareness of global warming, the security of the energy supply, and many other social and economic factors [5]. This outlook indicates that nuclear power will continue to play an important role in future energy needs, including providing base-load electricity.

Nuclear reactors designed, constructed and managed based on the best available technologies for safety at the time are still vulnerable to nuclear accidents and/or may be subject to increased impact from such an accident due to many technical, cultural and social factors, including design criteria; quality control during manufacturing and construction; system degradation over time; human errors in operating and maintaining the facility; natural hazards such as earthquakes, extreme weather conditions, tsunamis, and floods; and terrorism. An examination of the causes of the Fukushima Daiichi nuclear accident, together with a discussion of the lessons learned from different viewpoints may improve design criteria for nuclear plants and may result in safer use of nuclear energy in the future.

This presentation will begin with a brief overview of the Fukushima Daiichi nuclear accident, together with major progress and remaining challenges associated with nuclear disasters. Lessons learned from the Fukushima Daiichi nuclear accident are investigated and discussed, as objectively as possible, from different viewpoints. An ideal framework is proposed to prevent and/or minimize the disastrous effects of a nuclear accident.

FUKUSHIMA DAIICHI NUCLEAR DISASTER

The Fukushima nuclear disaster was the largest nuclear accident in Japan and the second-largest nuclear accident in the history of mankind, after the Chernobyl accident in 1986 in Ukraine in the former Soviet Union [6]. Unlike the Chernobyl accident or the Three Mile Island accident in Pennsylvania [7], the Fukushima Daiichi accident was a complex disaster triggered by a massive earthquake, followed by a giant tsunami. The earthquake caused overhead cables to sway and damaged transmission towers, resulting in the loss of an external electric power supply. Although all operating units were automatically shut down when the earthquake occurred and the backup diesel generators started automatically to provide emergency power, the power station in the basement was soon flooded by the tsunami, resulting in a “station blackout” (SBO). Thus, all motor operated pumps for cooling became inoperable, resulting in a situation called “loss of ultimate heat sink” (LUHS). In addition, the combination of the earthquake, the tsunami, and the loss of electric power, resulted in the inability to properly monitor and control the situation of reactors within the plant. Explosions occurred in units 1, 3 and 4, caused by hydrogen released from the damaged cores and trapped in the reactor buildings. A large amount of radioactive materials was released by the hydrogen explosions and spread over a large area. Because the plant is located in a coastal area, both the land and sea were contaminated by radioactive isotopes, mainly I-131, I-132, Cs-134 and Cs-137.

During and just after this accident, there was considerable confusion about the situation within the Fukushima Daiichi nuclear plant and about the information about radiation needed by citizens. Due to the lack of information on radiation levels, together with a lack of knowledge required to properly understanding the risks of radiation, not only the people living in the Tohoku region, but those living in the Kanto region, and even in Tokyo and other regions throughout Japan became panicky. Although the System for Prediction of Environmental Emergency Dose Information (SPEEDI) was available, it was not utilized to make decisions about emergency evacuation. An impressive message from the government, repeatedly voiced by Mr. Yukio Edano, the former Chief Cabinet Secretary, stated that “there should be no immediate health impact”. This message was frequently misinterpreted to mean that a “health impact will eventually occur in the future". Many people worried about the possible impact on the health of their children. Following a series of reports on the contamination of water, vegetables, fruits, ocean fishes, and rice, the daily lives of the people living in Tohoku and its neighboring regions became disordered for up to 2 years. Although food products are now under strict regulations, some people still worry about the possibility of eating radioactively contaminated foods.

The accident was followed by the development and evaluation of a variety of approaches to decontaminate soils, parks, roads and buildings, the debris from the tsunami, and water, and to reduce the volumes of plants and cow dung. Some of these efforts were effective and successful, but some technologies had limitations, especially when treating large areas of contamination [8].

The progress and status of the Fukushima Daiichi power plant can be determined from a series of reports issued by the International Atomic Energy Agency (IAEA) [9]. Although some progress has been made, the disaster remains a big, unresolved mess. Major problems include: 1) the need for hundreds of tons of water per day to cool the molten fuel; 2) the inability to decontaminate polluted water containing radioactive tritium; 3) the safe removal of spent fuel rods; 4) the safe and effective removal of molten fuel; 5) finding skilled labor to work at the Fukushima nuclear power plant; 6) stopping groundwater flow beneath the power plant to prevent further pollution of the sea and thus radioactive contamination of fish, a major food source and local industry; and 7) finding candidate sites for disposal of radioactive materials obtained during decommission on site and de-contamination off-site.

LESSONS LEARNED FROM THE FUKUSHIMA NUCLEAR DISASTER

After the Fukushima Daiichi nuclear power plant accident, many organizations and researchers have discussed the lessons learned from this tragic accident from different points of view.

On March 17, 2011, less than one week after the accident, CNN reported 5 early lessons learned from Japan's nuclear crisis [10]. These lessons included: 1) the world should build and operate modern nuclear reactors, suggesting the need for higher design standards and/or criteria; 2) countries should not be over-reliant on nuclear energy; 3) relying on nuclear energy requires significant know-how and resources, meaning that highly professional and technical resources are necessary to operate a plant, manage a crisis and deal with an accident; 4) companies and countries must plan for the worst; and 5) safety concerns must not take a back seat to energy production or prestige.

The technical analysis subcommittee within the society of Atomic Energy of Japan summarized the lessons related to seismic design, tsunamis, station blackouts, ultimate heat sinks, accident management, hydrogen explosions, cooling of spent fuel storage pools, promotion of safety research, safety regulations and safety design, organization/crisis management, information disclosure and safety management during an emergency [11]. Some short-term and long-term proposals were made in the document, but it will take a long time for these proposals to be implemented.

In a report the Japanese government submitted to the IAEA Ministerial Conference on Nuclear Safety in June 2011 [1], the lessons were divided into 5 categories. Category 1 summarized the lessons based on the occurrence of the Fukushima Daiichi nuclear power plant accident, and indicated the importance of strengthening measures to prevent severe accidents or damage from natural disasters such as earthquakes and tsunamis, failure to secure a necessary power supply, and loss of cooling functions. Category 2 indicated the significance of enhancing response measures to severe accidents, including enhancement of measures to prevent hydrogen explosions and ensure the operability of contaminant venting systems. Category 3 described the need to enhance responses to nuclear emergencies, including those associated with communications and environmental monitoring. Category 4 emphasized the significance of reinforcing safety infrastructures, including separating NISA from METI; the establishment and reinforcement of legal structures, criteria and guidelines; and ensuring the independence and diversity of safety systems. Category 5 indicated the importance of instilling a stronger safety culture.

There have also been detailed, technical discussions on the lessons learned from the Fukushima Daiichi accident for designing safer nuclear power plants. The IAEA [12] issued a document entitled "Preliminary Lessons Learned from the Fukushima Daiichi Accident for Advanced Nuclear Power Plant Technology Development" and illustrated some technologies that can increase the diversity of both the core and containment cooling systems and the ways these systems are powered; by, for example, gravity, compressed gas, AC power, DC power and/or natural circulation. The basic consideration is to provide options and create extra time for cooling during emergency conditions similar to those encountered during the Fukushima Daiichi accident, including loss of power, loss of cooling water flowing through the core and loss of the ultimate heat sink. Possible technologies include the use of passive reactor core cooling systems, such as pressurized core flooding tanks, elevated tank circulation loops, elevated ravity drain tanks, passively cooled steam generators via natural circulation, passive residual heat removal exchangers, and passively cooled core isolation condensers. In addition, passive systems for containment cooling and pressure suppression should be considered, such as containment pressure suppression pools, containment passive heat removal/pressure suppression systems, and passive containment spray systems. Additional technological options include containment design, the prevention and mitigation of hydrogen explosions, containment venting systems, instrumentation hardened against high radiation levels and spent fuel cooling.

The manufacturer of the Fukushima Daiichi nuclear power plant, Hitachi, also analyzed the lessons learned and made proposals for improving safety [13]. The lessons summarized by Hitachi included: 1) relocation of switchboards and other important equipment to better sites, utilization of portable equipment, and ensured access, 2) configuration and deployment of isolation valves, 3) provision of a backup DC power supply for important equipment, 4) instrument reliability and credibility, and measures for dealing with problems during an accident, 5) provision of wider ranges of water injection and cooling systems, 6) accessibility, ease-of-use, and effectiveness of accident management equipment, and 7) provision of alternative means for protecting containment vessels.

Some social scientists described the Fukushima Daiichi nuclear accident as a human disaster and stated that the electric company and the Japanese national government should be responsible for it, due to a series of "underestimations", including underestimations of the maximum height of a possible tsunami, the possibility of a "station blackout" and lengthy periods without AC power [14].

The Government Investigation Committee on the Accident at Fukushima Nuclear Power

Stations of Tokyo Electric Power Company (TEPCO) summarized and reported major issues related to the formulation of fundamental and effective disaster prevention measures, the lack of viewpoint on complex disasters, the attitude toward risks, the lack of a sense of crisis at administrative bodies and TEPCO, governmental crisis management systems, and information and risk communication. The government committee also pointed out the importance of "deficiency analysis from the disaster victim's standpoint", the importance of a safety culture vital to the lives of the public, and the necessity of continued investigation of the entire range of accident causes and damage [15].

The final report by the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC, Diet Committee) indicated that the accident was preventable [16]. The structure of the Fukushima Daiichi Nuclear Power Plant was not capable of withstanding the effects of the earthquake or the tsunami. Despite TEPCO and the regulators being aware of the risks of such natural disasters, neither had taken steps to put preventive measures in place. This was the fundamental reason for the accident. It could have been prevented if these matters had been attended to appropriately. The report also summarized problems with responses to the nuclear emergency, including problems with the responses by TEPCO and the national government, the emergency response led by the Kantei (Prime Minister's office) and government bureaucratic organizations, the emergency response by Fukushima Prefecture, and problems with the government's disclosure of information during emergencies. Organizational issues of the parties involved in the accident were criticized, and necessary measures to improve the legal system were recommended.

With references to the reports summarized by the Government and Diet committees, Dr. Tatsujiro Suzuki, the vice chairman of the Japan Atomic Energy Commission indicated 5 major lessons: 1) The Fukushima Daiichi accident was a man-made disaster and was preventable. 2) The emergency response system was unprepared. TEPCO, the regulators, and the central government were all ill-prepared to deal with a nuclear emergency. Miscommunication and mistrust among the regulators, the Prime Minister's office and TEPCO were the result of poor crisis management by the government. 3) There was a communication failure associated with protecting public health. SPEEDI was not used, and the government and regulators were not fully committed to protecting public health and safety. 4) The regulatory framework was controlled by the nuclear industry. Both reports emphasized the importance of the "independence" and "transparency" of newly established regulatory organization. 5) Information disclosure and sharing were insufficient. The lack of sufficient and timely information after the accident was an important reason for increased concern over the accident [17].

A recent document issued by OECD/NEA [18] summarized the response by NEA member countries, NEA initial considerations and approaches, follow-up NEA actions to the Fukushima Daiichi accident, and NEA direct support of Japan. Major lessons can be found from the key messages associated with assurance of safety, shared responsibilities, human and organizational factors, defense-in-depth, stakeholder engagement, and crisis communication. These key messages also addressed international aspects of emergency preparedness, trade and transport issues, and research and development. This document indicated that in-depth experience feedback from the Fukushima Daiichi accident will continue over the long term, for up to ten years or more.

IDEAL FRAMEWORK FOR REDUCING NUCLEAR DISASTERS

The lessons learned from the Fukushima Daiichi nuclear accident cover technical, organizational, legal and sociopolitical aspects. These lessons will continue to be identified and developed for a long time due to the complexity of the problem. Based on the lessons learned, we propose an ideal framework and/or process for reducing possible nuclear disasters in the future.

Site selection and characterization

Site selection should consider many natural and/or geological conditions, such as the location of earthquakes/active faults, floods due to tsunamis and/or unusually heavy rain, and possible loss of electric supply due to unusual weather conditions such as tornadoes and typhoons. Basically, necessary factors can be considered, but prediction and/or proper estimation may be difficult and insufficient due to the limitations of contemporary science and technology. Most of the large earthquakes occurring in recent years were unexpected, including the 1995 Great Hanshin, 2004 Indian Ocean, 2005 Pakistan, 2007 Sumatra, 2008 Sichuan, 2010 Haiti, 2011 Great East Japan (Tohoku earthquake), and 2012 Emilia earthquakes. In addition, many tragic floods in recent years were not predicted. Therefore, scientists and researchers should be aware of the limitations of modern science and technology. Over-trusting and overconfidence may result in tragic accidents caused by low-probability events.

Design criteria

All currently operating nuclear reactors passing stress tests meet current design criteria and/or standards. Taking into account the lessons learned from the Fukushima Daiichi nuclear accident, newly designed reactors will be safer than older reactors. Due to the changes in systems and/or increases in system complexity, however, caution must be exercised in designing new systems.

Material supply and construction

The materials used in building nuclear power plants should be strictly monitored. Defects may be present at extremely low probability even in high quality materials. Construction quality is also important, but sometimes cannot be well controlled due to the lack of highly-educated, professional, and/or experienced workers, especially in developing countries.

Operation, maintenance, emergency training and crisis management

Any material or system will degrade or deteriorate over time. Although higher quality goods deteriorate more slowly, long-term safe operation may result in complacency. Therefore, the importance of emergency training should not be overlooked. The JCO Criticality Accident that killed two people in Japan in 1999 can be regarded as due to absentmindedness and/or complacency. The Fukushima Daiichi nuclear accident also illustrated the problems associated with emergency responses, not only within TEPCO, but also in regulatory organizations, the central government and the entire system. The absence of such a severe nuclear accident before Mach 11, 2011, resulted in insufficient preparation for this type of severe accident.

Responsibility and regulation

The lead responsibility for developing nuclear power, and thus for a potential nuclear crisis, differs somewhat in different countries, but should be made clear. The primary responsibility for nuclear safety remains with the nuclear power plant operators, and regulatory authorities have the responsibility to ensure that the public and the environment are protected from the harmful effects of radiation. In case of an accident, emergency management organizations should share responsibilities with regulators and operators to effectively exchange and utilize information for public and environmental protection and to reduce the impact of the accident [18].

An ideal regulator should be independent from government and industry influence, open to the public, with sufficient employees having different professional backgrounds not only in nuclear science and engineering but in risk communication and other fields, and have strong connections with domestic and international experts in related fields.

Enlightenment and education

Radiation has been called an invisible fear in Japan. Due to the lack of enlightenment and education, many people have misconceptions that nuclear power plant accidents are the same as explosions of nuclear bombs. The lack of basic knowledge about radiological risk may increase the difficulty of risk communication.

Research and development

The safer use of nuclear energy requires that the causes of the Fukushima Daiichi nuclear accident be further investigated and examined. Dissemination of the lessons learned and the experiences gained in dealing with severe nuclear accidents can increase the credibility of the nuclear industry, its regulators, and the government. Research and development associated with decommissioning, treating water contaminated with tritium and decontamination should be increased. In addition, approaches and technologies related to the disposal of radioactive wastes, especially high level radioactive waste, should be further promoted to ensure that the nuclear industry has a sustainable future.

CONCLUDING REMARKS

The tragic events caused by the cascading effects of the Great East Japan earthquake resulted in an unprecedented nuclear accident at the Fukushima Daiichi nuclear power plant. While many lessons remain to be identified, the lessons learned to date may serve as warnings to nuclear industries and related organizations. This paper provides a concise overview of the Fukushima Daiichi nuclear accident, together with major progress made and remaining challenges associated with nuclear disasters. Based on the lessons learned from this accident, this paper proposes an ideal framework for preventing and/or minimizing the effects of disasters resulting from a nuclear accident.

The presentation is intended to stimulate discussions on safety issues associated with the use of nuclear power. The ideas and considerations provided in this presentation do not reflect the opinions or views of any organization, but are from a neutral point of view.

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