Lessons learnt from Fukushima Accident – What did McMaster Undergraduate Students learn ?

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Abstract

Nuclear communities not only in Japan but also around the world learnt a lot of lessons from the Fukushima accident. The direct cause of the accident from the viewpoint of traditional engineering is clear, and as a result various measures have been implemented around the world. The accident also provides many insights into the relationship between traditional engineering and Japanese society. In this paper, the root causes of the accident were studied by applying a psychological model for evocation of an individual's anxiety related to social affairs [1] to the discussions in an undergraduate course at McMaster University. In the last section, the challenges, which McMaster students considered Japanese nuclear community is now facing and Canadian nuclear community can contribute to in future, are summarized.

1. Introduction

Before March 11, 2011, 54 nuclear power stations (NPS) were online, and produced approximately 30 % of electricity consumed in Japan. Japan was the largest producer of nuclear power after the USA and France. At the time, the nuclear policy in Japan followed the Framework for Nuclear Energy Policy [2], which was put forward by Japan Atomic Energy Commission on October 11, 2005. On October 14, 2005, the Cabinet Council decided that the government would respect the Framework for Nuclear Energy Policy as a fundamental principle for research, development and utilization of nuclear science and engineering [3].

On March 11, 2011, the Fukushima Daiichi Nuclear Power Station Accident (hereinafter, Fukushima accident) occurred as a result of the Great East Japan Earthquake and the tsunami which followed. According to the report of the National Police Agency [4], 15,884 people were killed and 2,633 people were still missing, as of March 11, 2014. Additionally, as of December 26, 2014, 121,505 residents of Fukushima Prefecture have been forced to evacuate [5]. This means that the number of residents evacuated due to the Fukushima accident is much higher than the number of people killed by, or missing because of the earthquake and tsunami. According to the Reconstruction Agency of Japan [6], as of June 2, 1011, 124,594 residents were evacuated by the earthquake and tsunami. The author has frequently heard an opinion, especially from outside of Japan, that death is a more severe effect than displacement. Certainly the death is severe, but even after 4 years have passed, a fact that such huge number of residents is still forced to be evacuated is now severer in Japanese society. Complete destruction of local communities, conflicts between original residents and evacuees, conflicts among the generations of evacuees, conflicts between Fukushima residents and other non-Fukushima residents

and very slow restoration are adversely giving serious physical, health and mental impacts on the residents of Fukushima prefecture.

On September 10, 2014, the Japan Nuclear Regulation Authority (NRA) granted permission to make changes to the reactor installation of Sendai NPS Units 1 and 2. Japan Broadcasting Corporation (NHK) conducted a public opinion poll on the restart of Sendai NPS and the use of NPS in Japan, and published the results on November 10, 2014 [7]. According to the poll, 3% answered that the number of NPS should increase, 21% supported the maintenance of the status quo, and 37% and 30% said that the number of NPS should be reduced, and that all NPS should be stopped, respectively. During the General Election of the Japanese Diet on December 14, 2014, the Liberal Democratic Party (a Government Party in Japan) did not include nuclear energy as a part of their election campaign and as a result the energy, especially nuclear energy, policy in Japan is still unclear. Sendai NPS Units 1 and 2 and Takahama NPS Units 3 and 4 are considered to restart in 2015. But, in the amended legislation, after 40 years of operation NPS cannot be operated anymore. This means that, in principle, and in reality, it is impossible that new NPS will be built in the foreseeable future.

In such a situation, it is meaningful to discuss what the young students in Canada learnt from the Fukushima accident.

The direct cause of the Fukushima accident is quite clear from an engineering point of view, as mentioned later. Considering the current situation of safety debate on nuclear energy in Japan, it is necessary to consider not only the engineering aspects but also the psychological aspects of safety [8]. Yamazaki et al. [1] proposed a psychological model for evocation of individual's anxiety related to social affairs (hereinafter, the model), and could successfully explain the process to evocate and relieve the anxiety related to avian influenza. Horii required the 1st and 2nd year students of his undergraduate course in the Department of Liberal Arts, at the University of Tokyo to read the Interim Report of the Investigation Committee on the Accident at Fukushima Nuclear Stations of Tokyo Electric Power Company [9], applied the model to the discussions of the students, and found that the root causes of Fukushima accident are (1) the adverse effect due to division of specialties and specialization and (2) the psychology of the public to seek the absolute safety [10].

In this paper, the model was applied to the discussions which were carried out in the undergraduate course "4ES3 Special Topics of Energy Systems" at McMaster University (sixteen 4th year students in the Department of Engineering Physics) from the viewpoint of triple bottom line of sustainability (economic, environmental and societal sustainability), and the root causes of the Fukushima accident were examined. The information provided to the students was the Final Report of the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission [11], American Nuclear Society Committee Report [12], Information from U.S. Nuclear Regulatory Commission [13], and additional information from the instructor (the author) which is mentioned in the next section. The students were also encouraged to perform their own self-studies of students. Because the Report of the Investigation Committee on the Accident at Fukushima Nuclear Stations of Tokyo Electric Power Company which Horii used emphasizes mainly on technological factors, but the Final Report of National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission

emphasizes not only on the social background, but also on the technological background [14], the latter report was used in the course. Furthermore, the challenges that the undergraduate students in McMaster University considered were summarized.

2. Information provided by instructor

In the course, the following information was provided by the instructor for the students.

(1) Cause of Fukushima accident from an engineering point of view
The direct cause is the submergence of all metal clad switchgears and many power centers.

In order to make the students consider whether this was negligence of Tokyo Electric Power Company (TEPCO), the following information was also provided.

(a) TEPCO investigated the sediments carried by the tsunami caused by the Jogan Earthquake in 869 along the Pacific Coast of Fukushima Prefecture. They found sediments at an altitude of approximately 4 m in the north area of Fukushima, but could not find any sediment in the south area (Tomioka – Iwaki; Fukushima Daiichi and Daini NPS are located in this area) [15].
(b) According to the opinions of experts and professionals on earthquake before the Fukushima accident, there was no big earthquake along the trench of Fukushima. This is because the coupling between the plates is weak and because the plates slip each other before the distortion is induced. Therefore, the large energy is not accumulated [15]. This was also supported by the risk prediction of earthquake issued by the Headquarters for Earthquake Research Promotion on January 11, 2011 [16].
(c) A blackout in Japan was empirically restored within 8 hours. Hence, the blackout over 8 hours was not taken into account in the safety assessment.
(d) 15 NPS (6 Fukushima Daiichi, 4 Fukushima Daini, 3 Onagawa, 1 Higashidoori, 1 Tokai) are located along the northeast Pacific Ocean coast, and after the Great East Japan Earthquake, all NPS in operation were safely stopped, and no damage in the safety systems of these NPS has been reported. The safety functions against large earthquakes worked as designed.
(e) Even after the Fukushima accident, Turkey and other countries consider that the reliability of NPS in Japan against earthquakes is still high [17].
(f) Measures against tsunamis from a technical point of view are also simple and clear. Many measures have already been installed, some are being installed, and some will be installed in existing NPS.

(2) Accident management
According to IAEA [18], the concept of the defense-in-depth consists of the following 5 levels ((purposes): methods and means).

- Level 1 (Prevention): Prevention of abnormal operation and failures. Conservative design and high quality in construction and operation.
- Level 2 (Surveillance): Control of abnormal operation and detection of failures. Control, limiting and protective systems and other surveillance features.

- Level 3 (Mitigation): Control of accident within the design basis. Engineered safety features and accident procedures.
- Level 4 (Accident management): Control of severe plant conditions including prevention of accident progression and mitigation of severe accident consequences. Complementary measures and accident management.
- Level 5 (Emergency response): Mitigation of radiological consequences of significant off-site releases of radioactive materials. Off-site emergency response.

The 4th and 5th levels were not practically implemented in Japan before Fukushima accident. Now, measures against severe accident (the 4th and 5th levels) are legally required.

(3) Challenges on social and ethical problems
The followings were explained in the course:

(a) A large number of residents with the mental stress, which caused by prolonged evacuation life and collapse of local community, still exists.
(b) New discriminated individuals and groups are generated through compensation and radiation exposure.
(c) There is a difference in opinion between the younger and older generations about the prospect of restoration and returning to their home towns.
(d) Many residents consider in their mind that they cannot return to their own home towns forever, but the government and TEPCO have never mentioned it.

(4) Relationship between local municipality (political level) and utilities
The following information was provided in the course:

(a) We might be able to see the dependent attitudes and sponging attitudes of municipalities to the utilities. Sometimes, it appeared as explicit and implicit requirements of money, J-Village (a $130M soccer facility built by TEPC; it was contributed to Fukushima Prefecture after completion), or Shinkansen (bullet train), for example. Utilities seemed to be a mallet of luck, that is to say, they brought god fortune and riches to the municipalities whenever the municipalities wanted. Sometimes, governors and mayors used NPS as a tool of their political performance.
(b) A symbiosis relationship between the municipality and the utility will continue for 40 to 60 years. If the replacement of NPS is considered, it will continue for more than 100 years.
(c) Considering the time, cost, and other resources to look for a new municipality for hosting NPS, considering that if one NPS stops for one day, the utility lost approximately $1M/day, and considering that a governor has the means that can stop NPS based on the laws such as Fire Service Act, there was a possibility that it was not profitable for the utility to refuse the requirements of municipality.
(d) All utilities made a Safety Agreement with the local governments. This is a kind of gentleman's agreement, does not have any legal binding force, and is the fundamental of mutual trust. When the utility planned to do something new, they had to receive the permission of the local government in advance, based on the Safety Agreement. Since the utility did not want to make trouble with the

local government, they obediently responded to the governments' requirements although the requirements were not related to the safety of NPS.

(e) When the utility planned to install or exchange the equipment, system and concept, especially related to safety, the groundwork to the governor, mayor, assembly, and influential people was essential. It sometimes took a long time, and they sometimes required money. This was also influenced by the schedule for the election of the governor and the mayor. Usually, from one year before the election, the utilities could not propose to do something new to the local government. Based on (a) to (e) and others, there might be a possibility that the utilities lowered their motivation to take a measure to a smaller risk.

(f) Many local municipalities, where NPS are installed, wish to restart the operation of the NPS as soon as possible because of their severe economic situation. Even after the Fukushima accident, mayors on pro-nuclear position have been reelected in many cases. On the other hand, it is not clear how many NPS the utilities will seriously try to restart. This is because of new severe safety guideline and because of the distrust of utilities to the professional capability and the review process management of NRA.

(5) The position of TEPCO in electric power industry

The followings were explained in the course:

(a) TEPCO reigned as a nuclear energy community in Japan as well as electric utility industry. The behavior and decision of TEPCO influenced other utilities and nuclear policy in Japan. In Tokai Unit 2 (The Japan Atomic Power Company (JAPC); 100 km from Tokyo), the height of the breakwater was changed higher (from 4.2 m to 6.1 m). The construction had been nearly completed on March 11, 2011. The height of tsunami that hit Tokai Unit 2 was 5.4 m. This construction was initiated by the requirement of Ibaraki Prefecture (local government). Since JAPC did not need to negotiate with local government, JAPC started the construction smoothly. If TEPCO had voluntarily planned the construction to increase the height of their breakwater, TEPCO would have had to check the impact to other utilities as well as other NPS (Fukushima Daini and Kashiwazaki-Kariwa) of TEPCO at first. After that, TEPCO would have had to negotiate with central government, local governments, regulatory authority, fishermen unions and so on behind the scenes, and then discuss the issue officially. Immediately after TEPCO announced that they build the higher breakwaters, other utilities would have been required to re-assess the risk and take the adequate measures.

(6) Relationship between the municipality where NPS are operated and other municipalities

(a) The historical background among Hamadori, Nakadori and Aizu of Fukushima Prefecture was explained. A similar complicated historical relation also exists in other prefectures. In the case of Aomori where a NPS, enrichment facility, reprocessing facility, low-level radioactive waste repository, and high-level radioactive waste (HLW) storage facility are operated, the similar complicated relations among Shimokita, Tsugaru and Nanbu are present.

(b) Even today, many residents in Tokyo do not like to purchase foods and fishes produced in Fukushima Prefecture. It is behaviors and the utterances of the residents in Tokyo that wound Fukushima residents.

(7) Perception of aftermath

The followings were shown in the course:

(a) There was a large difference in knowledge on contaminated areas among the residents in Fukushima Prefecture, the residents in Tohoku region (except Fukushima), the residents around Tokyo, the residents in Western Japan, and non-Japanese living abroad, according to the investigation of Fukushima University [19]. The residents in Fukushima Prefecture correctly identified the contaminated area, the residents in Tohoku region considered that all Fukushima Prefecture was contaminated, the residents around Tokyo considered that all Tohoku regions were contaminated, the residents in Western Japan considered that all Eastern Japan was contaminated, and non-Japanese living abroad considered that all Japan was contaminated.
(b) Fukushima accident is now a story of the past for the people outside Fukushima.
(c) When Tokyo was decided to host the 2020 Olympic Games, the residents in Fukushima Prefecture said "that is a story in Tokyo, and is not our business".
(d) Risks are always forced on socially vulnerable people, leading to generating a new discrimination people/group in society. Nothing has changed since Minamata disease (1950) [20].
(e) From the standpoint of utilities & municipalities where NPS are operated, the nuclear energy should have been a privately run national program. But, the central government evaded the responsibility after the Fukushima accident.
(f) Credibility of experts and professionals on nuclear energy was completely lost.
(g) Washington D.C. knew important information such as the melt-down and those were shared among American experts, before Japanese experts, including nuclear experts, knew them.

3. Application of a psychological model for evocation of individual's anxiety related to social affairs

Based on the questions, "Why couldn't TEPCO and Japan prevent the accident?" and "Why couldn't they improve the safety measures?", the model was applied to the discussions of the students in the course, and the discussion points were extracted. The discussion points were reorganized and divided into some subgroups as follows;

- Limit of voluntary maintenance
- Lack of capability to evaluate the risk of tsunami
- Inappropriateness of review and amendment of Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities
- Inappropriateness of back-check on seismic design
- Requirement of zero risk by the public
- Bureaucracy in Japan
- Inappropriateness of measures on severe accident (tsunami)
- Lack of measures on tsunami
- Inappropriateness of internal investigation and discussion on tsunami in TEPCO
- Lack of communication among the specialties
- Lack of capability of regulatory authority
- Voluntary efforts on severe accident
- Severe accident measure limited only to internal events

- Spell to deterministic design concept
- Difficulty to deny the past

Then, the relation of causes and effects among these subgroups was studied (Fig. 1), and the root causes were decided; (1) lack of communication among the specialties and (2) requirement of zero risk by the public.

It was found that the latter is the same as that which Horii pointed out [10], and the former is also related to the adverse effect due to division of specialties and specialization that Horii pointed out. Importance of communication among the experts of various subdivided fields was pointed out in Hurricane Protection Decision Chronology related to Hurricane Katrina [21].

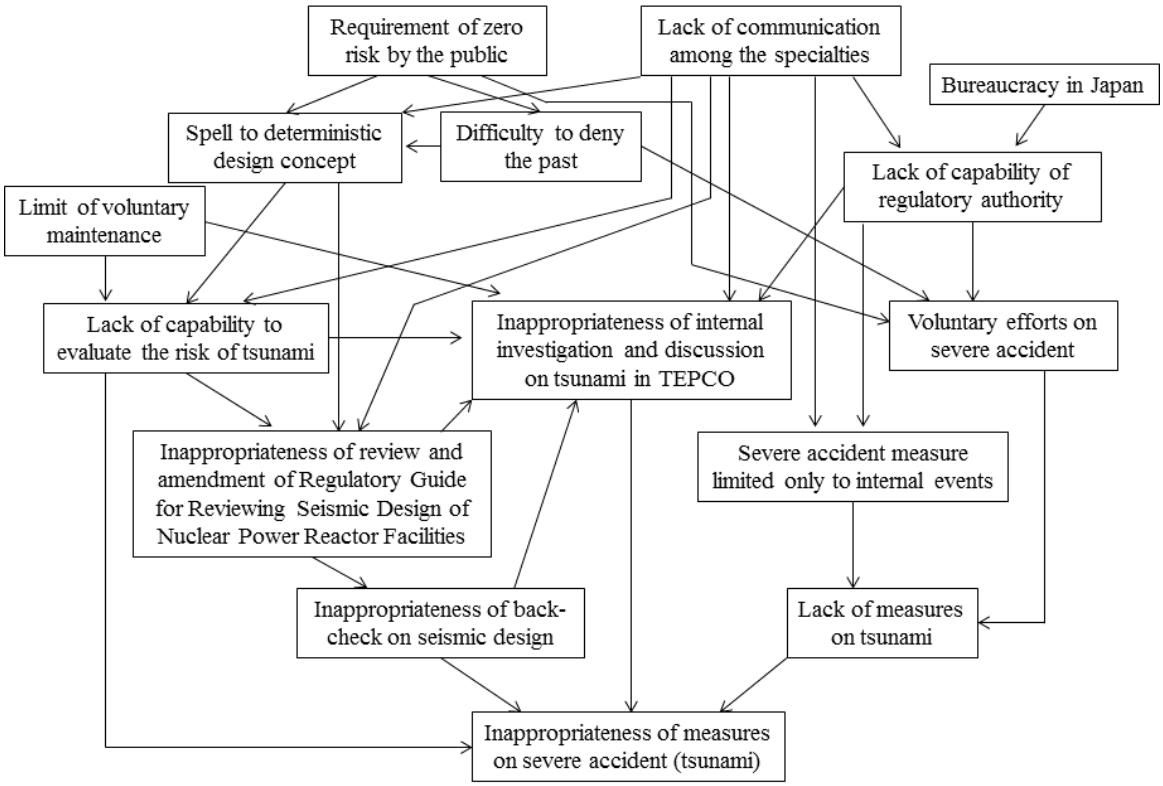

Fig. 1 Cause-Effect Relation in Fukushima accident

Information provided for the students in the course was different from that by Horii. The cultural background of Japanese students is different from that of the students in the course (no Japanese students were included), and the understanding on Japanese customs by the former may also be different from that by the latter. On the other hand, the students at the University of Tokyo belonged to

the Department of Liberal Arts, meaning that they did not have much technical knowledge on nuclear engineering, whereas all students in the course had a specialized education in nuclear engineering. In spite of these differences, the fact that the similar results were obtained suggests that the root causes in this paper and those found by Horii are considered to be valuable information to the nuclear energy society both in Japan and around the world.

4. Problems found from the discussion with Japanese colleagues

Following are the well-known important issues that must be addressed in order to advance the decommissioning in Fukushima NPS steadily.

- Development of technologies to identify, recover, store and manage the debris
- Reduction of volume of contaminated water
- Development of technologies to find the leakage points in the pressure and containment vessels, and seal them
- Confirmation of the soundness and safety of pressure and containment vessels which had been heated to high temperatures with seawater present
- Reduction of radiation level inside NPS

Through the discussions with colleagues in TEPCO, METI and others, other utilities and nuclear industries in Japan, the following additional challenges were revealed. The discussions were conducted from September to December, 2014, and reflected to the students' discussion in the course.

(1) Improvement of capability and expertise in regulatory authority and securing human capitals in nuclear industry

The number of students who applied to Department of Nuclear Engineering decreased in 2012 and 2013. Although it increased in 2014, it may decrease, again, because the nuclear policy in Japan is not clear [22]. Furthermore, the research field which many students want to study in the university is radiation for medical application, but not fission energy nor decommissioning/decontamination [23]. The number of participants in job fairs hosted by the nuclear industry of Japan was reduced to approximately 20%, compared to before the Fukushima accident [22].

In the bureaucracy of Japan, government officials transfer from one department to another department every two to three years and are promoted. It is difficult for the regulatory authority to accumulate the knowledge, skills and experiences within the authority and improve their capabilities. In the lifetime employment system of Japan, it is also difficult for the regulatory authority to recruit capable and skilled staff. A high skilled person is promoted in his/her company, and receives higher benefits than the regulatory authority could provide.

The decommissioning work does not produce electricity or any other benefits and as a result, it is not attractive to young generations. The nuclear energy society in Japan has to prepare a convincing answer to the question "Can I risk my career in decommissioning work?"

(2) How to reduce the tritium in contaminated water, and how to win the confidence of the fishermen who are worried about the damage to their reputation and how to protect the Pacific Ocean coastal states of which the public worries about the risks to fishing and marine sports.

The volume of contaminated water was approximately 600,000 tonnes as of December 2014. The volume increases by 300 tons every day. IAEA and U.N. nuclear watchdogs recommended Japan to consider the controlled discharges of contaminated water into the sea [24, 25].

Cesium-134 and -137 are removed from the contaminated water by a cesium adsorption facility. 62 radionuclides such as strontium-90 are removed from the contaminated water by the Advanced Liquid Processing System (ALPS), but tritium cannot be removed. Hence, all water processed is stored in the tanks as "contaminated" water. The fishermen in Fukushima Prefecture and some residents in the Pacific Ocean coastal states are worried about the hazard and the risk of tritium released into the Pacific Ocean. The development of technologies to remove the tritium from the contaminated water is desired, and the communication with the stakeholders is critical. Even after the tritium is successfully removed from the contaminated water, we must consider how to manage the waste containing a now higher concentration of tritium.

(3) Volume of waste drums generated by decontamination off-site of Fukushima Daiichi NPS

If the wastes generated by the decontamination works in Fukushima are simply packed into the 200 L drums, much more than 10 million drums might be produced.

JNFL (Japan Nuclear Fuel Limited) is now operating a low-level radioactive waste repository in Aomori Prefecture, and has been receiving approximately 11,000 drums every year. Japanese Government promised Fukushima Prefecture that the decontamination wastes will be transferred from temporary storage sites to an interim storage facility within 3 years, and to a final repository which will be built outside Fukushima Prefecture within 30 years. Suppose that the transportation and receiving capacity of an interim storage facility and a final repository is similar to that of JNFL. If a significant volume reduction is not achieved, or if a lot of storage facilities and repositories are not operated, it is obvious that the government cannot commit to the promise.

(4) Loss of public confidence to academia on nuclear energy

Before Fukushima accident, many experts and professionals on nuclear energy said that the risk of a NPS accident is negligibly small, and after Fukushima accident, they said that the scale and the impact of the accident were limited. They also denied the possibility of melt-down for a while. Many Japanese feel that they have been deceived by the experts and professionals on nuclear energy during and after the accident.

5. What did McMaster undergraduate students consider about their contribution to Japan?

Based on the root causes extracted by the model and the challenges revealed by discussions with Japanese colleagues, the students considered the challenges that Japanese nuclear community is facing and Canadian nuclear community can contribute to.

(1) Human capital

NRA periodically participates in the meetings with other regulatory authorities (Canada, USA, France, UK, etc.) to share information on top-management and on problems related to regulation. But, their problem on human capital is lying on the capability of staff engaging in the practice of regulation. Any country has some problems to be improved, but also has some innovative solutions in its regulation system. If the staff can stay in a partner country like Canada (Canada Nuclear Safety Commission) for one to two years, and learn the innovative solutions and regulation management, they can integrate what they learn in the partner country with the innovative solutions of their own regulatory body and improve the regulation practices in their own country.

Japan now focuses on the measures which will be used during and after the accident, but does not consider the measures to prevent the accident so much. It is valuable if the Canadian nuclear community including the students contributes to the development of measures to prevent accidents in Japan.

(2) Contaminated water

Ministry of Economy, Trade and Industry adopted three projects to evaluate the performance of tritium separation from the contaminated water and analyze the operation and maintenance costs [26]. One of the projects was proposed by GE Hitachi Nuclear Energy Canada Inc. The Canadian nuclear community has lots of experience with the management of the tritium, and if the students can follow and increase their experience, they can contribute to the contaminated water issue.

The BC Province in Canada is also one of the key stakeholders, when Japan will release the contaminated water into the Pacific Ocean, although radioactivity is less than international and domestic criteria of Canada. The Canadian nuclear communities including the students can collaborate with Japan to communicate with the people in BC. Such communication skills are also useful to build and strengthen the mutual confidence between the Canadian nuclear community and the Canadians.

(3) Waste management

Nuclear communities in the world consider that the Deep Geologic Repository project in Kincardine and Adaptive Phased Management program by NWMO are successfully progressing. In the former, Canadian government is expected to issue the license of low- and intermediate-level radioactive waste repository in 2015. In the latter, 22 municipalities expressed their interest to host the repository of used nuclear fuels in 2012. 16 Aboriginal and 30 Métis (namely, First Nations) communities were involved in this process. Now, the number of municipalities was narrowed down to 9 by NWMO’s review.

Futaba and Okuma towns near Fukushima Daiichi NPS decided to host an interim storage facility for decontamination waste, but it is very tough to advance the site selection of the final repository outside Fukushima Prefecture. Many Japanese outside Fukushima consider that the wastes generated in Fukushima should be disposed of within Fukushima. Japan also has a challenge to select a municipality to host a final repository of HLW which has already been generated and will be generated from the use of NPS. Furthermore, there is no societal agreement on the management of debris and the final figure on Fukushima NPS.

The experiences on communication with local communities including First Nations and the experiences to build the confidence relationship between Canadian nuclear community and Canadian society are valuable and useful to push the waste management programs in Japan forward.

(4) Restoration of public confidence to academia on nuclear energy

Japanese society criticizes that the professors of universities in Japan have received research funds from the nuclear industry, and comfortably and internally conducted the researches within the closed nuclear village. However, that research was found to be useless in the most serious emergency, and they could not prevent and mitigate the accident. Furthermore, they repeated the comments which profited TEPCO during and after Fukushima accident.

There is only a way to recover the public confidence in Japan. Japanese nuclear community should promote research and educational collaborations with Canada and other countries while ensuring the transparency to external societies.

6. Conclusion

By applying the psychological model for evocation of individual's anxiety related to social affairs to the discussions of undergraduate students in McMaster University, two root causes were extracted - the lack of communication among the specialties and the requirement of zero risk by the public.

Through the discussion with Japanese colleagues, several important problems which have to be solved to restore Fukushima and the nuclear energy in Japan were summarized.

The challenges, which McMaster students considered Japanese nuclear community is now facing and Canadian nuclear community can contribute to in future, are summarized. This type of discussion is considered to encourage the Canadian students to commit to a variety of problems Japan, Canada and other countries have.

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