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Reflections and Lessons from the Fukushima Nuclear Accident#

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Sub-Committee on Fukushima Nuclear Accident

Committee on Comprehensive Synthetic Engineering

Science Council of Japan

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Summary

The March 2011 Fukushima nuclear accident caused by a devastating tsunami in north eastern Japan uncovered serious flaws in the country's nuclear-safety management, regulations and researches.

We must learn from the lessons for our future.

One of the lessons is that the science community should take a leading role to restore mutually reliable relationship between the nuclear professionals and the public by promoting communications between them. It should be recognized that the decision to choose socially acceptable level of risk is one of the so-called trans-science issues, which cannot be solved by science only.

The importance of "integration of knowledge" should also be pointed out. One of the indirect causes of the Fukushima nuclear accident is a gap of the risk recognition on tsunami and earthquake between the geologists and the nuclear professionals. The knowledge of the geologists had not been properly transferred to the nuclear specialists. For securing nuclear safety, it is required to integrate knowledge in many academic fields, not only nuclear science and technology, but also those of other academic fields including medicine, biology, ecology, social sciences, and humanities. The Science Council of Japan, which consists of the scientists from all academic fields, could provide the most appropriate place to implement the integration of knowledge for nuclear safety and other areas as well.

Chapter 1 of the present report describes the background and the purpose of the report.

Given in Chapter 2 is what happened to the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station with the estimated amount of released radioactive materials to the environment by the above accident when the Great East Japan Earthquake accompanied tsunami occurred.

Chapter 3 describes the history of the efforts to develop the nuclear power reactors in Japan. The accidents and troubles of nuclear power reactors and their safety measures in Japan in the past five decades are in particular stressed.

The emerged challenges in the introduction, the construction and the safety measures of nuclear power reactors in Japan in the past, along with their background and the reconsideration matters for the future, are given in Chapter 4.

Since a nuclear power plant is a highly complex artificial system, we need to make the most conscious effort to keep and improve its safety taking a holistic view of the whole system. As a complex system is generally composed of wide variety of technological disciplines, a small gap between such fields can be a possible defect of the system leading to the initiator of a major accident. Then, we discuss in Chapter 5 the principles for the safety of complex systems in

addition to advancing revisions in light of the Fukushima Accident, which include the defense in depth for nuclear power plants, the nuclear emergency response, the nuclear safety regulation system, the communications needed to establish the fundamentals of safety, the safety research and the responsibilities of academia.

Chapter 6 concludes the report.

Contents

* Appendices 1, 2 and 3 are available only in the Japanese version, but not in the current English version since the essential point of the report will not be affected without these. If necessary, refer to the Japanese version at < http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-h140613.pdf >.

1. Introduction

The March 2011 Fukushima nuclear accident that followed the tsunami in Japan uncovered serious flaws in the country's nuclear-safety management, regulations and researches. After a few years from the Accident, we must reflect upon the road to the Accident and the path we have taken since our nuclear deployment started in the middle of the 20th century. Especially, the responsibility of the Japanese academia is serious and we must learn from the Accident for our future.

As is well known, electric power achieved by nuclear energy has resulted in the activation of the Japanese industry and economy. In addition, radiation has been utilized in the medical field as well as industrial and agricultural sectors, contributing to the development of diagnosis and treatment.

However, light and shadow coexist in nuclear application. The Fukushima Daiichi nuclear power plant accident was one that this latter aspect was very largely manifested. The Fukushima nuclear accident is a typical example of the shadow mentioned above, that is, nuclear safety is not absolutely guaranteed, and people realized at heart that there is a big risk in nuclear power in other words. Also it was revealed that people had not sufficiently been informed that there is a great risk in the nuclear plant. Furthermore, we failed in accident management to minimize the damages from the Accident. The responsibility of scientists in the above context is quite import

Japan has had a high ability from before the World War II in the study of nuclear physics, but the major research facilities were destroyed by the Occupation Forces (GHQ) after the War. In 1949, the Science Council of Japan was established. After the San Francisco Peace Treaty in 1951, some of the Japanese researchers wanted to restart the research related to nuclear physics or its peaceful use. But, their plan was not allowed at that time with the concerns that lead to the development of nuclear weapons.

In the meantime, Atoms for Peace speech was delivered by the United States President Eisenhower at the United Nations with the background of the East-West Cold War after the World War II in 1953. Corresponding to this speech, national plan of peaceful use of nuclear energy was initiated in 1954 on the grounds that the nuclear power was required for the reconstruction of the country after the War. The Science Council of Japan was in favor of this decision on the condition that three principles on peaceful uses of atomic energy were met. Since there was an understanding that the above three principles, especially "Non-secrecy", that all the information was publicized, would halt military research, the principles were included as it is to the Atomic Energy Basic Law.

In 1957, the Science Council of Japan held the first nuclear symposium and the Atomic Energy Society of Japan was established in 1959 with the backing of the Science Council of Japan. The above symposium has been held every year since 1963, cosponsored by the Science Council of Japan and a number of academic societies. The Science Council of Japan has also proposed to the government to build several facilities for nuclear study.

About the Three Mile Island (TMI) nuclear power plant accident in March 1979, the Science Council of Japan held a symposium in cooperation with the Nuclear Safety Commission in November of the same year. But, little was done to establish a full-fledged management system for disaster mitigation based on the task analysis for the organizational management at the time of the accident, which was known very important in such accident as the TMI accident. In other words, no actions or proposals were not given for the crisis management system against the worst case by the Science Council of Japan nor the academic societies in Japan.

In 1986, the Chernobyl accident occurred in the Soviet Union. The International Atomic Energy Agency (IAEA) summarized accident report with the database of relevant articles as accident archive of the International Nuclear Information System (INIS). Aiming to establish a system of information sharing about the accidents or the failures of nuclear plants, the collaboration between the Institute of Nuclear Power Operations (INPO) and the World Association of Nuclear Operators (WANO) was also initiated. Though it was recognized among Japanese nuclear engineers and scientists that the above international activities included various important methodologies about accident management, decontamination, radioactive waste treatment, and reputational damage control and so on, these were not well developed in Japan unfortunately.

The number of Japanese nuclear power plants during this period increased dramatically. The Tokai JCO criticality accident of 1999 had revealed that narrow sense of nuclear technology could not solve the nuclear safety problems in general. Discussion about the accident management and safety issues were not enough even after the accident.

After the Fukushima nuclear accident, several accident reports were published. But a number of issues still remain unsolved.

In this report, we will first summarize the accident based on the information at the present time. Next, in order to analyze the background and factors that led to the accident, we look into several problems of the past nuclear power development and regulations in Japan, which were manifested by the accident. The challenges that the scientific community must tackle are followed.

It is noted that the contents of this report are focused on nuclear power out of the various use of nuclear energy in order to avoid the distraction.

2. Overview of the Great East Japan Earthquake and TEPCO's Fukushima Daiichi Nuclear Power Station Accident

Described here is what happened to the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station when the Great East Japan Earthquake accompanied tsunami occurred and about the amount of released radioactive material to the environment by the accident.

(1)The Great Earthquake and the Nuclear Accident

There have been six Boiling Water Reactors (BWR) at the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station. The total electric output was 4,696 MWe.

The disastrous earthquake (the Great East Japan Earthquake) with the magnitude 9.0 occurred at 14:46:18, March 11 in 2011. At the time of the earthquake, Unit 1, 2 and 3 were operating at rated power level. Unit 4 was in a periodic inspection outage, and largescale repairs were under way. Unit 4 fuel had all been relocate to the spent fuel pit (SFP) in the reactor building. Units 5 and 6 were also in a periodic inspection outage, but the fuel remained in the reactor core area of the reactor pressure vessel, and the reactors were in a cold shutdown condition.

The earthquake brought Units 1, 2 and 3 to an automatic shutdown because of the high seismic acceleration. The off-site power supply was also lost because of damage to the transmission towers from the earthquake. For this reason, the emergency diesel generators (EDGs) for each unit were automatically started up to maintain the function of cooling the reactors and the SFPs. Normal reactor cooldown and decay heat removal functions were under way.

About 41 minutes after the earthquake, the tsunami arrived with an estimated maximum wave height of 15 m, which was much larger than the seawall at 5 m.

All AC power for units 1-5 was lost when emergency diesel generators and switchgear rooms were flooded. The seawater intake structure was severely damaged and was rendered nonfunctional. All DC power was lost on units 1, 2 and 4, while some DC power from batteries remained available on Unit 3 because some of those battery banks were not flooded. One air-cooled emergency diesel generator continued to function and supplied electrical power to Unit 6, and later to Unit 5, to maintain cooling to the reactors and spent fuel pools.

With the loss of all AC power, all safety and non-safety system driven by AC power became unavailable.

With no core cooling to remove decay heat, core damage began on Unit 1 on the day of the event. Steam-driven injection pumps ware used to provide cooling water to the reactors on units 2 and 3, but these pumps eventually stopped working, at 13:25 on 14th and 2:43 on 13th, respectively. As a result of inadequate core cooling, fuel damage also occurred in units 2 and 3.

In the process, the zirconium in the fuel cladding reacted with water to generate a great deal of hydrogen. This hydrogen leaked out to the reactor building via containment vessel with the volatility radioactive material and hydrogen explosions occurred at the reactor buildings of the units1, 3 and 4, at 15:36 on 12th, 11:01 on 14th and 6:12 on 15th, respectively. These hydrogen explosions scattered radioactive debris to cause contamination in the site and brought about hindrance to the work to the convergence of the accident.

Fuel has damaged in units 1-3 of the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station because of ①all the external and emergency powers were lost and ②all the function of cooling and removing heat from the core has lost. As a result, large amount of radioactive material has released to the environment and gave impact on the environment.

(2) Large-scale release of radioactive materials

The trend of radiation level at the several locations of Fukushima Daiichi Nuclear Power Station Site boundary such as main entrance and west gate (the distance from the nuclear reactor building is 1 - 2 km) shows sharp and large peaks on 15th and 16th March and after that continuous release from 20th to 22th, March. Further investigation is necessary as some of the radioactivity peaks can be assumed to be related with the vent or hydrogen explosion, but others are difficult to relate with them.

The Tokyo Electric Power Company has evaluated the total amount of radioactivity released to the air by the dose rate measured by the monitoring car. The amount of radioactivity is calculated to reproduce the measured value by repeating the evaluation.

The total amount of radioactivity released to the air which was evaluated by this way was 500PBq for rear gas, 500PBq for Iodine 131, and 10PBq for Cesium 134 and 137.

The estimation period was from 12th to 31st, March as the amount of radioactivity released to the air after April is less than 1% of that of in March.

In addition to Tokyo Electric Power Company, Japan Atomic Energy Agency, Central Research Institute of Electric Power Industry and so on have evaluated the total amount of radioactivity released to the air. As for the atmospheric release, most evaluation shows 120-200PBq for Iodine 131, 9-20PBq for Cesium 137 and 9-20PBq for Cesium 134. 500PBq for Iodine 131 by TEPCO is larger than the other evaluations.

Tokyo Electric Power Company has evaluated the total amount of the radioactive material released to the ocean by reproducing the dose rate measured by the radioactivity concentration near the outlet. The main cause of the marine pollution is release from a head gate of unit 2 and 3, release of the low concentration water from radioactive waste building, and the low concentration groundwater of sub-drain pit. In addition, fallout from the atmospheric release and wash out by rain.

The evaluation results show that 11PBq for Iodine 131, 3.5PBq for Cesium 134 and 3.6PBq for Cesium 137. The Evaluation period was from 26th March to 30th September.

Many organizations and researchers had evaluated the total amount of the radioactive material released to the ocean and most evaluation show that 9-13PBq for Iodine131, 3-6PBq for Cesium 137 and 3-6PBq for Cesium 134.

3. Development of Nuclear Power Reactors and the Efforts in Japan

This Chapter describes the history of the efforts to develop the nuclear power reactors in foreign countries and in Japan. The accidents and troubles of nuclear power reactors and their safety measures in Japan are in particular described.

(1) History of the development of nuclear power reactors

① Development of nuclear power reactors in foreign countries

After the “Atoms for Peace” speech by President Eisenhower at the United Nations in 1953, the development of nuclear power reactors started officially in the world. The Calder Hall Nuclear Power Station with the graphite moderated CO2 cooled reactor started the operation in the United Kingdom in 1956. The light water reactors (LWR) were developed in the USA, and the Shippingport Atomic Power Station with Pressurized Water Reactor (PWR) started the operation in 1957.

In the USA, the nuclear power stations with the LWRs were constructed in areas approaching gradually to the residence area. As the safety measures for public, the Emergency Core Cooling System (ECCS) for prevention of the core meltdown accident, and the Containment Vessel (CV) for prevention of the radioactive materials release were equipped from the Shippingport Atomic Power Station. Thus the Engineering Safety Features were equipped and the basis for the Defense-in-Depth for safety measures was established.

② Introduction and construction of the nuclear power reactors in Japan

First national budget for the nuclear power was determined by the Diet of Japan in 1954. In 1955, the nuclear three laws including the nuclear basic law were established, and the Japan Atomic Energy Research Institute (JAERI) was founded. Thus the basis for the development of nuclear reactors was built. In 1957, the Japan Atomic Power Company (JAPC) was established, and it was decided to import the Calder Hall type reactor from the United Kingdom for the Tokai Nuclear Power Station. However, the reactor was not enough for anti-earthquake design and the CV was not equipped. The design of fuel bundles were then changed to cope with the earthquake, alternate functions for containment vessel were equipped, and the multiple emergency shutdown functions were equipped. The power reactor was constructed and started the operation in 1966.

The electric power companies started to examine the introduction of the LWRs from the USA in around 1960. In preparation for that, the Japanese Government sponsored the SAFE (Safety Assessment and Facilities

Establishment) Project research on the effectiveness of the engineering safe guards of LWRs such as the ECCS and the CV cooling system from 1963 to 64. Basing on these efforts, the electric power companies decided to introduce the PWR from the Westinghouse (WH) and the Boiling Water Reactors (BWR) from the General Electrics (GE) in the USA. The first order was the BWR for Tsuruga Power Station No. 1 by JAPC in 1965, and the orders for BWRs and PWRs were succeeded. Tsuruga No. 1 was started the commercial operation in March 1970. Initial plants have been constructed by full-turn- key contract and GE or WH designed and constructed. The electric power companies were only to turn the key for operation. Mitsubishi Heavy Industries (MHI) undertook a part of manufacturing the PWR and Toshiba and Hitachi a part of the BWR. These companies took the roll of prime constructor of the plants from the second unit.

The operated plants, however, experienced the initial stage troubles, such as the Stress Corrosion Crack (SCC) et al, and the plant capacity factor was low. Then the Government and the industrial companies conducted the 1st and the 2nd Improvement and Standardization Programs from 1975 to 1980. Nuclear Power Engineering Center (NUPEC) was established to carry out the verification tests. Further the Advanced BWR (ABWR) and the Advanced PWR (APWR) were developed by incorporating new technologies in the 3rd Improvement and Standardization Program from 1981 to 1985.

(2) Safety measures for nuclear power reactors

① Initial safety measures

The codes and standards of light water reactors were prepared for the design and construction of the plants in the USA. The Japanese government made Japanese codes and standards by studying the USA codes and standards. Among them the guideline for siting criteria was included and the comments by the civil and environmental engineers were reflected in the Japanese guideline. The most important safety measure for nuclear reactors was the prevention of the core meltdown accident, and the issues were the capability of the ECCS and the cooling characteristics of the fuel at the rupture of large coolant pipes. As the safety research for the light water reactors in Japan, the JAERI started the ROSA (Rig Of Safety Assessment) tests on the reactor cooling at the Loss of Coolant Accident (LOCA) from 1970. The results were internationally utilized and trained researchers of the JAERI technically supported the regulatory agency. On the other hand, the radiation leaking incident occurred during power-up test of nuclear powered ship “Mutsu” in the Pacific Ocean in 1974. In the wake of the incident, the regulatory system for the nuclear power was reformed and the Nuclear Safety Commission (NSC) was newly established in October 1978. The safety review conducted by the Ministry of International Trade and Industry (MITI) for the establishment of nuclear power stations was doubly checked by the NSC.

② TMI and Chernobyl Accidents, and the Severe Accident

Three Mile Island (TMI) unit 2 accident occurred in March 1979 in the USA. The accident initiated almost the same phenomena as the small break LOCA. However the operation miss made it to the accident with the destruction of the core and the melting of the fuels in the reactor. Before the accident, Professor Rasmussen of MIT reported the Probabilistic Risk Assessment (PRA) of Nuclear Power Stations in 1975. The report included the larger risk for small break LOCA than for large break LOCA, and the TMI accident corresponded to it. After then the safety (or risk) assessment using PRA method promoted actively in Japan. The TMI accident occurred half a year after the establishment of the NSC, and the NSC took out the 52 items reflecting to the safety measures in Japanese nuclear power plants.

After the Chernobyl accident in 1986, the Japanese Government started to manage the Severe Accident (SA). The NSC started the examination of the corresponding policy, and the MITI started the researches on the SA at the NUPEC. The NSC put out the policy in 1992 that the NSC strongly encouraged the licensee to prepare voluntarily the Accident Management (AM), and to carry out it accurately at the emergency. This was substantially close to the regulatory requirements and bore comparison with foreign countries at that time.

In 1995, as a unified view for the SA, the agreement was made at OECD/NEA to consider the SA measures from the design stage for new reactors. After then it was included in regulation in foreign countries. In Japan, the draft of private voluntary standards for new reactors was reported in 1999. However, the defense-in-depth measures for SA in Japan have not progressed compared with foreign countries. The final approval by the regulatory body for the upgraded AM of the licensees was in 2002. But the budget of safety research for light water reactors was gradually decreased by the reason that the light water reactors had been technically proven. This weakened the expert groups engaged in nuclear plant safety in Japan. Besides strengthening the experts corresponding to the emergency, the organizational cooperation among central and local governments and licensees was necessary for the safety of residents around the nuclear power stations, and the prior simulation and the training were very important. However the emergency governance postponed remaining insufficient.

③ Actions for accidents and troubles

In the 1990s, the 15 nuclear power plants including ABWRs of Kashiwazaki-Kariwa nuclear power station units 6 and 7 of Tokyo Electric Power Company (TEPCO) started the commercial operation. In this period, however, many accidents and troubles occurred consecutively. They were the break of the unit

3 recirculation pump of Fukushima-Daini Nuclear Power Station of TEPCO in 1989, secondary pump sodium leakage accident of Fast Breeder Reactor MONJU of PNC (Power Reactor and Nuclear Fuel Development Corporation) in 1995, and the JCO (Japan Nuclear Fuel Conversion Co.) critical accident at Tokai in 1999.

The licensees and regulatory bodies were chased to the corresponding accidents. The drastic safety measures were not made progress and the technology systems for nuclear power usage were not reconsidered and not improved enough. Holistic response capability including the risk management and the crisis management by taking into account the SA measures for the TMI and the Chernobyl accidents in other countries were not cultivated, staying at the technical development by introducing from other countries. Then it was said as “the lost 10 years” and entered into 21 century with the cooped-up feeling of 1990s. As the restructuring of the Government Ministries and Agencies, the Nuclear and Industrial Safety Agency (NISA) was established as the regulatory body for nuclear power stations in 2001. However, the fraud in the inspection of the CV by TEPCO became apparent in August 2002, and the secondary loop break accident at Mihama unit 3 occurred in August 2004 leading to the death of five workers. The NISA successively chased to these problems and time passed.

④ Earthquake and tsunami

The safety review guideline for seismic design was revised by the NSC in 2006, in which the Kobe Earthquake in 1995 was taken into account. In the guideline, the Tsunami damage according to the off Sumatra earthquake on the Madras Nuclear Power Station in India was also reflected in the investigation of the committee. As the accompanying events of the earthquake, the stability assessment of the slope around the nuclear power plants, and the safety review for tsunami were added in the guideline. As the lessons learned from the disaster of Kashiwazaki-Kariwa nuclear power station of TEPCO caused by the off Niigata Chuetsu earthquake in 2007, the fire protection measure and the installation of the seismic isolation building were prescribed to the licensees from the regulator.

Though the recognition on the importance of Tsunami was not so high among the nationals and even the experts, it became interested by the Tsunami damage at off Tokachi earthquake and at off Sumatra earthquake in 2003. National Institute of Advanced Industrial Science and Technology (AIST) conducted the survey of Tsunami sediment from the Jogan earthquake in 869 mainly at Miyagi Prefecture. However during the survey, the Great East Japan Earthquake occurred. Without the essential scientific discussion and without the deep worst case discussion among the experts for earthquake, civil engineering, seismic design, and nuclear power, including the government officials, the Fukushima Daiichi Nuclear accident occurred.

4. Emerged Challenges and their Background

This Chapter describes the emerged challenges in the introduction, construction and the safety measures of nuclear power reactors in Japan, along with their background and the reconsideration matters for future.

(1) Trend to introduce overseas technology

Light water reactors in Japan were introduced from the USA, at first by the full-turn-key contract. Under the contract, the safety assurance was based on manufacturing the systems and components completely according to the design drawings in the USA. After then, however, due to the efforts such as the Improvement and Standardization program and the development of the ABWR and APWR, the manufacturers in Japan became to lead the world.

Safety standards in the USA were also introduced to Japanese regulation by almost translating them. In the USA, the codes and standards of the American Society of Mechanical Engineers (ASME) such as the structural design codes and the rules for in-service inspection were used for nuclear power plants. Accordingly the regulatory authority of Japan also used them as the Ministerial Ordinance and Notice by translating in Japanese. ASME's Code & Standards were, however, the paid publication, and ASME claimed to use them free in 1980s. The Japanese Government did not want to pay and the Ministerial Ordinance and Notice were not revised though ASME revised them. As the solution for this problem, the JSME started to make the Codes and Standards for the structural design of nuclear and thermal power plants. For the similar purpose, the Standard Committee was installed in the Atomic Energy Society of Japan. Since the technologies are steadily progressing today, the use of academic societies with a mass of researchers and engineers are very important, particularly, for the codes and standards. How to make, enact and use the effective codes and standards is an important challenge.

Large scale calculation code is another problem. For the complex event analysis and the safety evaluation of large scale nuclear power plants, large scale numerical calculations for safety analysis are necessary. In Japan, the calculation codes for safety analyses were introduced from the USA around 1970. The USA companies allowed the code usage for the accuracy improvement of the codes by reflecting the safety research results by the JAERI et al. After the middle of 1990s, the USA companies frowned the use of the codes with free of charge. Then the research road map to develop the large scale computer codes was prepared at the Academic Societies in Japan. The development of safety analysis codes is very important for nuclear power plants safety, in which the requirements by the industries and the regulatory body are included. By taking care of the interrelation between the experimental data and the calculation models, the development of the reliable codes is very important for resolving the complicated events.

Nuclear power plants consist of the comprehensive technologies. Problem is that the troubles and the accidents are apt to occur from the boundary of each technological area. At the beginning of the plant introduction, the experts from each technological area worked together, cooperated and discussed on the nuclear power plants. After then the nuclear related departments were established in the universities to educate and to study the nuclear power as the comprehensive technologies. Until now, however, the electric power companies have adopted very few PhD students from the PhD course of the graduate school. This shows that the electric power companies were not keen to solve the technological essence deeply. On the other hand, progress in science and technology made the technological area subdivided into many academic fields and the cooperation of experts in these wide areas became difficult. Whether the efforts by the researchers and engineers for safety assurance of nuclear power systems would be inherited, or whether the inheritable technology systems would be constructed, are the challenge.

As shown above, though the Japanese manufacturing companies are leading the world, they do not lead the world in the overall design and technical capabilities and in strategy. In order to enhance the nuclear safety, comprehensive powers such as readiness, robustness, multiplicity, goods and human resources, restoring force and so on are required.

(2) The safety assurance and the regulation in advanced science and technology era

Advanced science and technology era began almost in 1980s and this era required the speed. Could the safety assurance and the regulation deal with this era?

The Supreme Court decision for Ikata nuclear power station justice required to take the latest technological knowledge into account for safety assurance. The Justice required the revise of laws and ordinances as soon as possible according to the development of the knowledge. It was a problem for the person in charge in the regulatory body, since they have not sufficient expertise, and it took the time to revise the laws and ordinances. It is very important for the person in charge in regulatory body to have the specialty by understanding the latest technical knowledge quickly and accurately. Previously, they relied on the specialists committee with the part time members of mainly the university professors. However it is very important to establish the expert organizations with responsibility and with authority to conduct the advanced work and to make the judgement by themselves.

Next is the concept of safety assurance in new era. After the Great East Japan Earthquake and Fukushima Daiichi Nuclear Power Plants Accident, the word “Unexpected” was very often used. Today, many artifacts are designed and manufactured, and many assumptions including the status of the use and the environmental conditions are supposed. In that case “Unexpected” occurs with two kinds. The first “Unexpected” is the true unexpected and no one could consider that it may happen. On the other hand, construction of the sturdy equipment for preparing the disaster once in several ten thousand years requires enormous cost. In that case the realistic equipment is designed and manufactured. Disaster occurrence exceeding the design is the second “Unexpected”. We may suffer the damage in the case. Then this case should be conveyed enough to the public for preparing the damage to be a minimum.

The large Tsunami of Great East Japan Earthquake was very close to the first Unexpected. However, after the 3.11, it belongs to the category of second Unexpected. Though today is in advanced scientific and technological era, our knowledge is very limited. From now the large eruption of volcanos, the meteorite falls and so on are considered to happen. Not only the safety assurance of the equipment design for nuclear power plants, but also assuring the defense-in-depth protection including the crisis management for unexpected accident, would cope with unexpected events.

(3) Situation to ensure the nuclear safety in Japan and the lost 20 years

Important deal for the safety assurance in Japan has in many cases been taken up after the USA dealt with. The research and development should steadily be done for the safety assurance of nuclear power systems. The steady research and development is also important for the technology transfer to the next generation. From the over-confidence that the light water reactors were technologically proven, the research budget on light water reactors at the JAERI decreased gradually after the middle of 1980s. This lead to the decrease and weakening of the research scientists and engineers in Japan and arose the problems in technology inheritance. In the USA, eleven national nuclear research institutes including the military exist with about 50 thousand employee, and it is possible to use them when it is needed. Existence of high level scientists and engineers is very important for the safety of nuclear power. It is the big challenge to use the giant and complicated artifacts safely for a long time, not limited to the nuclear power.

In Japan, “the lost 10 years” was said for nuclear power at about 2000, and 10 years passed. It was said “the lost 20 years” at about 2010. There existed many important issues such as the delay of the introduction of the SA to the regulatory requirements which has been introduced in foreign countries, the delay of the introduction of rational regulation for safety assurance based on the risk which proceeded in western countries, the downturn of the plant capacity factor, the ambiguous restart condition of stopped plants and the ambiguous back-fit condition of new standards. Further split of the regulation for nuclear into several Ministries and Agencies, and retard of the deal for international criticism including IAEA et al. that the regulatory body NISA was an Agency of METI (Ministry of Economy, Trade and Industry) which promoted the nuclear power, were the issues. However, NISA chased to the occasional problems, and the big revolution did not proceed. This is related to the closed relation among the electric power companies, the manufacturers, the regulatory authorities, and the scientists and engineers for nuclear power, which is called as the "nuclear village". Thus the nuclear power in Japan proceeded its own way by sticking to the partial improvements which were different from the world, and lost the sight for overall cornerstone picture. It is important in nuclear power to pursue the most important issues for the safety assurance, which is the real safety culture. It should strongly proceed to solve the essentially important issues without sticking to the occasional problems.

One of the main causes of "the lost 20 years" was the deal in current information society. The information which was previously not announced by the reason that it is not sure was leaked and said as "information hidden." Appropriate action for that was difficult, and the information including inaccurate one through the various media governed the Japanese society. For such situation, the regulatory body often forced to the licensee the action which was not important for the safety point of view and took time and effort.

The safety measure should be based on the risk in today's advanced science and technological society. Establishment of the risk concept is an important issue in Japan. The word "Absolute Safety" has often been used in nuclear, though there is nothing "absolutely safe" in nuclear and even in any artifacts. The discussion based on the risk concept could not proceed, and the explanation to the people was thought to be changed from "there is no need to worry since it is made safely", "we don't cause the accident", and "it is absolutely safe". The issue is that such barren discussion continued for a long time, and there were no essential discussion such that "where is the problem and what we should take care", "how to proceed the further safety assurance measure" and "how evacuation should be in emergency." Background of them is the inadequate education including the primary and the secondary education, for nuclear power, radiation and radioactivity. Since the radiation and radioactivity is the source of nuclear risk, the education should actively proceed. Further it is necessary that the experts for the risk management should be nurtured and organized.

5. Nuclear Safety Issues and Responsibility of Academia

Since a nuclear power plant is a highly complex artificial system, we need to make a conscious effort to keep and improve its safety taking a holistic view of the whole system. As complex systems are generally composed of wide variety of technological disciplines, a small gap between such fields can be a possible defect of the system leading to the initiator of a major accident. We need to clarify principles for safety of complex systems, in addition to advancing revisions in light of the Fukushima Daiichi accident.

(1) Defense in depth for nuclear power plants

The objective of securing safety in nuclear facilities is to protect people and the environment from harmful effects of ionizing radiation. To achieve this objective, design basis with sufficient margins should be established in addition to prepare multi-layers of protection to avoid the possible accident beyond the design basis of the systems. This is the basic concept of "Defense in Depth" (DiD), which is an effective principle that should be used to design nuclear power plants, even after the Fukushima Daiichi accident. The concept of DiD can be used not only in design of hardware, but also in operation and management of the systems during normal condition and in case of emergency.

As well as to strengthen the design criteria to external initiators by earthquake, flood and other phenomena, safety should be secured by multiple and multilayered measures for the power supply for water injection and cooling systems. Accident management (AM) measures should also be improved to be effective under actual severe accident environment.

Setting the protection level for natural phenomena is always accompanied by the difficulty based on the uncertainty. Since it is extremely difficult to get all the possible accident progress scenarios that may occur in the case of severe accidents beyond the design basis, flexible use of portable equipment will be effective AM measures. In addition, sophisticated judgment and leadership of individuals, and management of organizations are important in an emergency case.

Probabilistic risk assessment (PRA) should be properly used to confirm various safety measure. Structures and procedures of operation and maintenance should be continuously improved to reduce the risk, even though the existing risk is small. Risk of a severe accident with damage of core fuels beyond the design basis has generally been recognized. However, compared to the multi-layered protection from internal trigger of systems, structures and components in the plant, sufficient protection measures were not prepared for external initiators, especially for tsunamis in Fukushima Daiich Nuclear Power station. During the Fukushima Daiichi accident, safety functions in many SSCs were lost simultaneously because of inundation by the tsunami wave exceeding the design basis height, resulting in damage of the reactor core and release of large amount of radioactive materials to the environment. Other plants in Onagawa and Tokai Daini nuclear power stations succeeded to avoid severe accident by the use of various measures; such as an initial decision to elevate the site of the plants to avoid the risk of tsunami, or improvement of watertight barrier for sea water pumps through a gradual review of postulated tsunami height based on updated knowledge.

(2)Nuclear emergency response

There was confusion in relation to the emergency response during the Fukushima Daiichi accident. Evacuation and sheltering were effectively operated based on the plant condition and were gradually extended to 3, 10, and 20 km, without dependence on prediction systems such as ERSS and SPEEDI. Deterministic health effects to residents by radiation exposure can be avoided. However, there were victims from patients in hospitals, because their evacuation was not properly performed.

The planning of nuclear emergency response should be developed based on the principles for radiation protection and safety. According to the standards of the IAEA for emergency protective measures, preventive protective measures should be prepared in advance based on the plants status. These come from the limited available information about the event progress in the initial stage of the accident and large uncertainty in the predictive evaluation of off-site exposure dose. The evacuation and temporary relocation should be carried out only when safely viable, but should not be possible if there is life-threatening condition during the evacuation. Also sheltering should be as short as possible until evacuation and relocation can be feasible in a safe manner.

In order to achieve the goal protecting the health of residents in the emergency management, clarification of the responsibilities of emergency related institutions is very important in corresponding to the progress of the accident. These protective measures for nuclear emergency will be properly integrated with the corresponding emergency arrangements other than nuclear disaster.

(3)Nuclear safety regulation system

Scientific rationality is a key for nuclear regulation system to achieve nuclear safety with trust from the public. Currently new regulatory standards have been enacted by the Nuclear Regulatory Commission in Japan. Continuous improvement in the regulatory system is also strongly required on the basis of the latest scientific and technological knowledge. Furthermore, risk informed regulation should be adopted, and a graded approach, which assigns resources based on risk, is required in regulator not only operators. A global assessment of latent defects related to important measures and the oversight of significant risk is more important than making efforts to examine details of the specific risk.

It is also an important role of regulator to set safety goals to consider the activities and measures to be implemented properly and effectively. The regulatory body should decide the requirements for performance, and the codes and standards developed by academic societies should be adopted as the specification codes for regulation after a strict review process. Collaboration with industries, academia, and other government organizations should then be achieved simultaneously with securing independency of regulation.

It is considered necessary to point out that human resources are important on a national basis. The government should maintain its crisis management capability collecting and evaluating knowledge-base required to make a global decision on regulation. Human resources with personnel management system for experts in the regulatory body should also be established properly.

(4)Communication common to various aspects to establish fundamentals of safety

Communication is an important factor common to various aspects of challenges for nuclear safety. Nuclear power plant, which is an integrated science and technology, is required to make a decision for continuous improvement based on communication between different stakeholders. As was seen in the lack of essential discussion and risk information exchange to determine the design basis tsunami height in the Fukushima Daiichi Nuclear Power station, the common understanding between the different disciplines is extremely important. Nuclear safety experts should have a bird's-eye view with high ethical standard and play an important role to take the initiative to communicate with stakeholders with different background.

(5)Safety research for the future

Researchers tend to be engaged deeply in their own subjects, and their efforts are usually concentrated on their specialized areas. In contrast, safety of complex systems may collapse from the gap between the disciplines and technical areas.

By maintaining a holistic point of view to secure nuclear safety, maps of technical challenges should be prepared based on the real capacity of current technology. In addition, roadmaps to achieve these challenges and safety goals should be prepared and implemented, and continuously improved considering safety importance of these issues and their time flame to complete the research outcomes.

Safety research is expected to point out the potential problem to provide early warning based on new scientific knowledge. It is also strongly important to collect and share the findings from operational experience of nuclear facilities from all over the world. In addition to the systematic safety research on risk management from wide variety of possible events including external initiators, it is requested that to advance overall discussion and research on communication, risk perception and related software issues.

It is also noted that studies on the security issues are important along with the safety research topics, while they are not easy considering information disclosure. To keep researchers with high scientific and technological capabilities is the key to ensure the effective safety research.

In addition, intensive research for robotics to be applied to wide variety of severe accident conditions and necessary decommissioning processes is strongly needed involving interdisciplinary research fields of academic societies. This collaborative activities should be based upon the experience in the accident at the Fukushima Daiichi Nuclear Power plants [4, 5].

(6)Responsibility of the academia

Various negative aspects due to the use of the nuclear energy have become apparent in the accident at the Fukushima Daiichi Nuclear Power plants in Japan. Scientists must play the responsible roles for nuclear safety based on the "Code of Conduct of Scientist" [1], which was revised by Science Council of Japan in January 2013. It is the responsibility of academia to share the basic concept and knowledge for nuclear safety.

The Atomic Energy Society of Japan, which has published its own investigation report [2] in March 2015, based on the Report of the Nuclear Safety Division on the Fukushima Accident [3] and other major investigation committee reports, will be one of the major academic society to make continuous contribution to clarify the lessons of the accident, concrete measures and future challenges for the decommissioning of Fukushima Daiichi plants for about 40 years, recovery of contamination in the surrounding environment, reconstruction of the regions.

It would also be the responsibility of academia to show the positive aspects nuclear power as a concrete choice in the future. To ensure the safety of nuclear power plants, there is a strong need to promote comprehensive initiatives in light of the characteristics of a huge complex systems involved deeply in the our current society. To enhance inter-disciplinary research infrastructure with holistic perspective, as well as disseminate the results across the human resource development and promoting a variety of dialogues. These efforts can contribute to welfare of human, safety of society and the sustainability of the global environment restoring the confidence to nuclear power by the public that has been lost by the Fukushima Daiichi nuclear accident.

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6. Concluding Remarks

(1) Roots of the Fukushima nuclear accident

Though we had experienced various nuclear accidents including those at TMI and Chernobyl, we could not prevent a severe accident caused by a huge tsunami beyond the design basis, leading to enormous damages on people and the environment. The basic roots of the accident lie in our negligence of continuous systemic efforts to maintain the safety of nuclear power plants as a large and complex artificial system.

(2) Lessons learned from the Fukushima nuclear accident

It is evident that safety measures in Japan were focused on the levels to prevent severe accidents, and that accident management to cope with severe accidents beyond design basis was not enough. It is urgently needed to plan and prepare severe accident managements to prevent evolution of the accidents caused by external events such as earthquake, tsunami, and terrorism, and to demonstrate the effectiveness of emergency response to a possible large scale release of radioactive materials by training in advance.

Since the limited available information of the event progress on the accident in advance, it is important to clarify the responsibilities of emergency related institutions to strengthen the leadership at site, as well as to prepare flexible response measures such as movable equipment. Emergency management requires both integrity and flexibility, and to realize these requirements, it is important to maintain flank and open communications among the related institutions including those for safety regulation.

It is necessary to use the concept of risk for setting indices to judge a level of nuclear safety. We should communicate with public on the risk of severe accidents as well as make further efforts to disseminate scientific knowledge on the risk of radiation exposure.

Multi-layers of protection with the concept of defense-in-depth against the emergence and developments of accidents are fundamental requirements to secure nuclear safety. To achieve the fundamental requirements, it is required for regulatory authorities, power companies, and related scientists and professionals to share safety related information and knowledge to exert consolidated power keeping in mind that safety is the first priority in nuclear power.

(3) Roles of science community

Scientists must play responsible roles for nuclear safety based on the "Code of Conduct of Scientist" (http://www.scj.go.jp/en/report/code.html), which was revised by Science Council of Japan in January 2013. While scientists will continue to participate in the public processes related to nuclear safety, they should conduct as neutral professionals apart from any specific interest of organizations or authorities.

Next, scientists should initiate the studies to minimize burdens on the next generations cooperating with the professionals of various fields and the practices on the damaged sites. Japanese scientists in the field of nuclear power could not forecast the damages of local communities by the released radioactive materials to bring about such large societal problems as to make even discussions for future recovery visions difficult for a long time. They assumed severe accidents like Chernobyl could not occur in Japan, thus, did not seriously prepared for possible huge social impacts by a severe accident. The scientists should reflect what they can do to restore the local communities in damaged areas taking into account the risk caused by the damages of harmful rumors.

Science community should take a leading role to restore mutually reliable relationship between nuclear professionals and the public by promoting communications between them. It should be recognized that the decision to choose socially acceptable level of risk is a problem of so-called trans-science issues, which cannot be solved by science only but still be discussed by scientific community.

It is required for effective nuclear safety regulation and emergency management to foster human resources and organizations having viable capacities of crisis management as well as the knowledge on nuclear safety. We should restore the academic basis concerning nuclear safety from the ground up.

Lastly, the importance of “integration of knowledge” should be pointed out. One of the indirect causes of the Fukushima nuclear accident is a gap of the risk recognition on tsunami and earthquake between geologists and nuclear professionals. The knowledge of the geologists was not properly transferred to the nuclear specialists. For securing nuclear safety, it is required to integrate the knowledge in many academic fields, not only nuclear science and technology, but also those of other academic fields including medicine, biology, ecology, social sciences, and humanities. Science Council of Japan, which consists of the scientists from all academic fields, could provide the most appropriate place to implement the integration of knowledge for nuclear safety.

Appendix 4. Current Status of Radiation Exposure for the General Public in Fukushima Prefecture

The radiation exposures due to the Accident are 1) for the workers involved in the reactor decommissioning work of the power plants or decontamination work of the environment and 2) for the general public exposed by radiation due to the environmental radiative contamination in Fukushima prefecture. Here the radiation exposure for the general public is discussed.

The effect of radiation exposure on public health is mainly contribution to cancer development for the low level exposure. Since cancer development results from many factors, it is difficult to identify epidemiologically the effect of radiation exposure under 100 mSv. For low level exposure, thus biological data play an important role.

International Commission of Radiation Protection (ICRP) shows the criteria for judgment, in the case of uncertainty or argument for the radiation effects are exist, because the scientifically balanced judgement based on peer reviewed data will be requested. Since the risk estimated in ICRP reports are supported by many scientists in the field of biological effects of radiation, present discussions are based on the risk estimated by ICRP.

(1) Current status of radiation exposure: Status of radiation exposure for the general public in Fukushima prefecture.

High dose rate area has been restricted for living and was divided into three categories: Evacuation Directive Lift Prepared Area is < 20mSv/y, Restricted Habitation Area is 20 ~ 50 mSv/y and Returning Difficult Area is >50mSv/y.

The estimation of personal exposure has been carried out by the committee of Health Checkup Survey in Fukushima [1]. The estimation of external exposure was carried out using an estimation system developed by National Institute of Radiological Science from the gathered data on behavior records.

The handout of the 19th committee held on May.18, 2015 gave the number of gathered data was 556,917cases and the estimation of external exposure for 540,638(97.1%) cases was completed at the end of Mar. The distribution of personal exposure is given in Table.1 where the data for people (whose estimated periods are less than 4 months and radiation workers were excluded).

The results for internal exposure for the public from the survey conducted by Fukushima prefecture showed that the number of survey was 178,630 in a period from 27 June, 2011 to 31 January, 2014, and the committed effective dose distribution was 178,644 for less than 1mSv, 14 for 1mSv, 10 for 2mSv and 2 for 3mSv[2].

Table 1 Estimation of cumulative external effective dose for the general public except radiation workers(mSv)

Effective dose	<1	1～2	2～3	3～4	4～5	5～6	6～7	7～8	8～9
No. of people	281,446	143,718	25,003	1,465	495	376	228	114	73
Effective dose	9～10	10～11	11～12	12～13	13～14	14～15	>15	MAX 25mSv	
No. of people	39	34	31	13	12	6	12		

Exposure for thyroid of children due to radioactive iodine was measured by a simple test using NaI(Tl) survey meters during the period between March 24, 2011 and March 30, 2011 for 1,080 children ranging from 0 years old to 15 years old in Iwaki city, Kawamata town and Iitate village. The distribution of thyroid dose was 55% for 0 μSv/h, 99% for less than 0.04 μSv/h and all children were less than 0.2 μSv/h. The Nuclear Safety Commission at the time judged that the equivalent dose for thyroid were less than 100 mSv[3].

(2) Future exposure

The IAEA report “Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience”[4] gives the estimation for accumulated external effective dose for 70 years after the accident caused by deposition of ^{137}Cs in the unit area[4]. The average normalized effective external dose to the adult population in the intermediate zone of Chernobyl contamination are given in Table 2.

For the radioactive contamination by the Chernobyl accident at the early time the contribution due to short lived nuclei possibly high compared to the Fukushima NPP accident, because of the higher temperature of nuclear fuel for the Chernobyl. On the other hand the ratio of ^{134}Cs/^{137}Cs is 0.55 for the Chernobyl accident and 1.0 for the Fukushima NPP accident. The contribution of ^{134}Cs is important to the ratio of accumulated dose of 70 years dose to the first year. The larger contribution of ^{134}Cs leads to a lower value of the ratio of accumulated dose of 70 years dose to the first year. Furthermore the extensive remedial actions were taken in Fukushima NPP accident gives a lower value. Thus the ratio might be low for the Fukushima NPP accident than the Chernobyl accident.

Table 2 Average normalized effective external dose to the adult population in the intermediate zone of Chernobyl contamination

		E/σ_{137} # ($mSv \cdot kBq^{-1} \cdot m^2$) of ^{137}Cs				
		1986	1987-1995	1996-2005	2006-2056	1986-2056
Russian Federation	Rural	14	25	10	19	68
	Urban	9	14	5	9	37
Ukraine	Rural	24	36	13	14	88
	Urban	17	25	9	10	61

σ_{137} is given for 1986.

(3) WHO estimation of the effect for radiation exposure due to the Fukushima Nuclear Power Plant Accident

WHO released the health risk assessment due to The Fukushima NPP accident [5],[6] and [7]. After Fukushima NPP accident, the general public was exposed to radioactive material through four major exposure path ways. These were 1) external exposure from radionuclides deposited on the ground, 2) external exposure from radionuclides in the radioactive cloud, 3) internal exposure from inhalation of radionuclides in the radioactive cloud and

4) internal exposure from ingestion of radionuclides in food and water. The exposure data are based on the levels of effective dose and thyroid doses calculated for the first year given in the WHO preliminary dose estimation report [6]. Lifetime organ doses for thyroid, colon, breast and bone marrow were calculated from the data. Lifetime organ doses were used to calculate lifetime attributable risk (LAR).

For purpose of the health risk assessment four distinct geographical areas were identified based on estimated doses for first year, as described below,

Group 1: the two locations in Fukushima prefecture with effective doses of 12-25 mSv, location ① and ② in Fig.1;

Group 2: the two locations in Fukushima prefecture where effective doses between 3 and 5 mSv, location ③～⑭ in Fig.1;

Group 3: the less-affected locations of Fukushima prefecture and the rest of Japan, where effective dose values are around 1 mSv;

Group 4: the neighboring countries and the rest of the world, where effective doses are well below 1 mSv.

Here the most contaminated area ① is Namie town and the second ② is Iitate village.

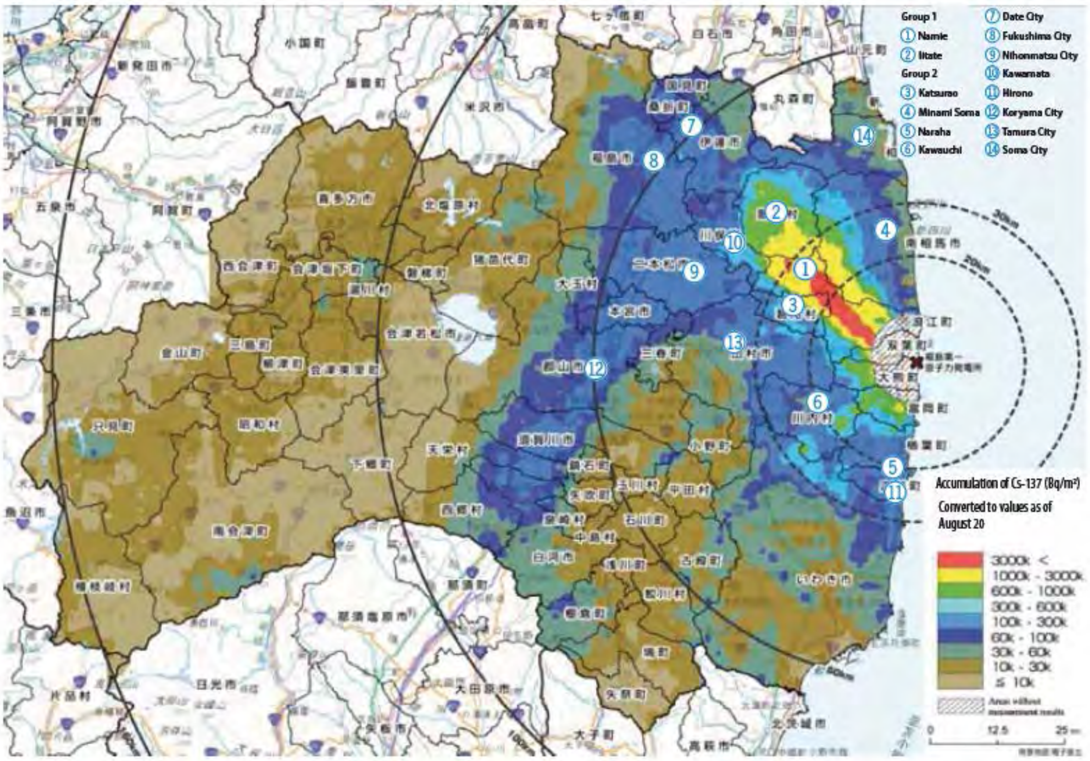

Fig.1 Locations in Fukushima prefecture considered in the assessment (Group 1 and Group2). Note that the rest of Fukushima (less affected) is part of Group 3.

The lifetime dose is given by the ratio of long-term dose to the first -year dose. This ratio is 3 for the Chernobyl accident. WHO used the ratio of 2 for Fukushima NPP accident, because a number of remedial actions were taken by Government of Japan, municipal authorities and residents quite soon after the accident to lower radiation exposure. Since locations ① and ② were specified as planed evacuation area, people in this area evacuated to less contaminated areas soon after the accident, the lifetime doses are similar as the first year doses.

The health risk assessment based on the following conservative assumptions to avoid any underestimation of doses. 1) The relocation of inhabitants in the planed evacuation area was assumed to take place after four months, 2) Those living in Fukushima ate only food produced in Fukushima. 3)All the food monitored was on the market although the dataset included the results of food samples that were collected for monitoring purpose and were not allowed on the market.

Table 3 Lifetime attributable risk (LAR) and lifetime baseline risk (LBR) for all solid cancer, Leukaemia and breast cancer [5]

one year old age-at-exposure

Region	All solid cancer			Leukaemia			Breast cancer	
	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (females)
①	27.0	0.730	1.113	26.3	0.040	0.027	27.7	0.357
②	15.8	0.425	0.647	15.3	0.023	0.016	16.1	0.205
LBR		40.60	29.04		0.60	0.43		5.53

10 years old age-at-exposure

Region	All solid cancer			Leukaemia			Breast cancer	
	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (females)
①	26.2	0.568	0.859	26.3	0.020	0.014	25.9	0.222
②	14.8	0.317	0.479	14.7	0.011	0.007	14.5	0.122
LBR		40.71	29.09		0.58	0.41		5.54

20 years old age-at-exposure

Region	All solid cancer			Leukaemia			Breast cancer	
	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)	Total lifetime exposure (mSV)	LAR ($\times 10^{-2}$) (females)
①	23.3	0.394	0.591	22.4	0.015	0.009	24.2	0.129
②	13.5	0.225	0.336	12.9	0.008	0.005	13.8	0.072
LBR		40.74	29.07		0.57	0.40		5.55

Here the health risk estimations for the most contaminated of location ① and ② are given in Table 3 and Table 4[5]. Table 3 shows the lifetime attributable risk and lifetime baseline risk for all cancers, leukaemia and breast cancer for a one-year old age-at-exposure, for a 10-year old age-at-exposure and for a 20-year old age-at-exposure. Table 4 shows lifetime attributable risk and lifetime baseline risk for thyroid cancer for a one-year old age-at-exposure, for a 10-year old age-at-exposure and for a 20-year old age-at-exposure. The baseline risks in the Tables are based on the lifetime risk up to attained age 89 for cancer incidence in Japan.

Table 4 Lifetime attributable risk (LAR) and lifetime base line risk (LBR) for thyroid cancer [5]

one year old age-at-exposure

Region	Thyroid cancer		
	Total lifetime exposure (mSv)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)
①	122.3	0.118	0.524
②	74.1	0.071	0.317
LBR		0.21	0.77

10 years old age-at-exposure

Region	Thyroid cancer		
	Total lifetime exposure (mSv)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)
①	96.1	0.054	0.245
②	52.5	0.029	0.133
LBR		0.21	0.77

20 years old age-at-exposure

Region	Thyroid cancer		
	Total lifetime exposure (mSv)	LAR ($\times 10^{-2}$) (males)	LAR ($\times 10^{-2}$) (females)
①	64.0	0.019	0.088
②	35.2	0.010	0.048
LBR		0.21	0.76

(4) The effect of radiation exposure due to Fukushima NPP accident: Summary of the estimation of the radiation effects

WHO released the summary of the estimation for the radiation effects as a news [7] as follows.

1) A comprehensive assessment by international experts on the health risks associated with the Fukushima Daiichi nuclear power plant (NPP) disaster in Japan has concluded that, for the general population inside and outside of Japan, the predicted risks are low and no observable increases in cancer rates above baseline rates are anticipated, however, that the estimated risk for specific cancers in certain subsets of the population in Fukushima Prefecture has increased and, as such, it calls for long term continued monitoring and health screening for those people.

2) In terms of specific cancers, for people in the most contaminated location, the estimated increased risks over what would normally be expected are:

・all solid cancers - around 4% in females exposed as infants;
・breast cancer - around 6% in females exposed as infants;
・leukaemia - around 7% in males exposed as infants;
・thyroid cancer - up to 70% in females exposed as infants (the normally expected risk of thyroid cancer in females over lifetime is 0.75% and the additional lifetime risk assessed for females exposed as infants in the most affected location is 0.50%).

3) For people in the second most contaminated location of Fukushima Prefecture, the estimated risks are approximately one-half of those in the location with the highest doses.

(5) The effect of radiation exposure due to Fukushima NPP accident: Risk associated with evacuation

Nomura and others of Univ. of Tokyo described the risk associated with evacuation in "Mortality Risk amongst Nursing Home Residents Evacuated after the Fukushima Nuclear Accident: A Retrospective Cohort Study"[8]. They analyzed data obtained from five care homes in Minamisoma. All elderly residents who had been admitted to the five facilities between March 11, 2006 and March 11, 2011 were included in their study. Evacuation history was given by the facilities. Many residents had multiple evacuations. They interviewed facility presidents to obtain care home-specific evacuation details. To assess the impact of the earthquake on mortality, death incidence density before and after the earthquake was calculated as number of deaths divided by sum of person-years at risk. The crude relative mortality risk was calculated as the ratio of post- and pre-earthquake mortality incidence densities. After of the earthquake, 75 residents out of 328 residents were died in one year after evacuation328 residents. The risk increased 2.7 times of the one before evacuation. The increased in mortality were highly dependent on facility-specific factors. Significant increases in mortality after earthquake were shown in three facilities, and the initial evacuation was associated with twice as many deaths as subsequent evacuations. There was also a substantial difference in mortality risks across facilities. These differences may be affected by factors such as residents' psychological state or health condition at the time of evacuation, facility-specific evacuation patterns, and the conditions in evacuation sites to which elderly evacuees were admitted. Evacuation distance did not show a significant influence on mortality in their study.

The decision to evacuate was driven by concerns about radiation risk which is very difficult to estimate at the time when a clear picture of the accident is not known. The evacuation, however, has adverse effects especially on vulnerable residents not only an increase of mortality but also bad influence on clinical status relevant to lifestyle diseases, and leads to an increase in cardiovascular events or other chronic disease sequela. Despite this, fear of radiation exposure in the affected area was severe enough to make evacuation inevitable: almost all residents of Minamisoma city evacuated in a relatively short period. Questions, therefore, about the safety of evacuation of elderly residents and how best to balance the competing risks of radiation exposure and evacuation mortality are of paramount importance.

Finally, the authors remarked their study shows that even under the extreme circumstances experienced in the aftermath of the Great East Japan Earthquake and subsequent radiation accident, some facilities were able to ensure that their residents suffered no significant increase in mortality risk. Balancing the competing risks of radiation exposure and evacuation mortality is of paramount importance when infrastructure collapse and damage do not themselves warrant evacuation. Health planners, disaster coordinators and facility managers in areas that may be subject to similar disasters should consider the lessons of Minamisoma, Fukushima when developing their own plans for disaster response.

(6) The effect of radiation exposure due to Fukushima NPP accident: Critical information for evacuees when they return to where they were before

When the evacuees return to where they were, they have to judge themselves. The evacuees should be able to understand the risk due to radiation. They therefore should be taught about the health risk due to radiation exposure and be given the circumstance where they measured their exposure themselves.

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