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Lessons Learned from Response to the Accident at the TEPCO Fukushima Daiichi Nuclear Power Plant: from the Viewpoint of Radiation Emergency Medicine and Combined Disaster

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Since the JCO criticality accident in 1999, it has been thought to be prudent to prepare a system for radiation emergency medicine. The Great East Japan Earthquake measuring 9.0 on the Richter scale occurred in Japan on March 11, 2011, and this earthquake and tsunami caused serious damage to the Fukushima Daiichi Nuclear Power Plant (NPP) of Tokyo Electric Power Co. (TEPCO). Hospitals that had been designated as radiation emergency facilities lost their function because they were located in the evacuation areas, and community lifelines such as water supply and electricity were severely damaged. However, hospitals not thusly designated could not receive patients from NPP because of concerns about the health effects of radiation from patients. In Japan, local governments with nuclear facilities such as NPPs run the training system of radiation emergency for medical professionals. However, those without nuclear facilities do not have the system. Therefore, education and training were restricted to related organizations and agencies. From the response to this accident, we learned that all hospitals, their staffs and first responders need knowledge about radiation and the basics of radiation emergency medicine. The response to this accident has also highlighted the challenges of a radiation emergency medical response system for a combined disaster. In our efforts for recovery from the damages, reconstruction of the medical system for radiation emergency in the affected areas has to be accelerated, since reactors have not been stabilized and many workers are still involved in recovery work, with high risks of radiation exposure at the NPP site. From our response to this combined disaster of earthquake, tsunami, and radiation, we also learned that there is an urgent need for an all-hazards approach.

1. Introduction

Since the discovery of X-ray in 1895 and radioactivity in 1896, humans have been using radiation in a variety of fields, such as industry, agriculture, medicine and others. Today, devices and locations from which an individual could be exposed to, or contaminated by radioactive materials are not scarce. On the other hand, radiation accidents fortunately occur only rarely. However, when a radiation accident does occur, expertise for responding to a nuclear and radiological accident is required. Radiation emergency medicine includes both dose assessment of patients exposed to radiation and/or contaminated with radionuclides and their medical care. Medical response to a radiation emergency means providing first aid and taking appropriate actions as for other accidents. The only difference from the

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response to other accidents is the need to protect yourself and others against radiation exposure[1]. Thus, involvement of radiation protection experts is required for the response. In a radiation accident, medical care by medical staff at local hospitals and first response by first responders such as local fire fighters and emergency medical technicians (EMT) are provided. A major problem, of course, arises from the fact that there are few medical professionals with the experience of caring for patients involved in radiation accidents, for the simple reason that such occurrences are not common, as mentioned above. Moreover, knowledge of radiation exposure and contamination with radioactive materials is usually lacking in these responders, including medical doctors, since radiation emergency medicine is not included in the curriculum of their educations.

The Great East Japan Earthquake occurred in the Pacific coast area of eastern Japan on March 11, 2011, and this earthquake and tsunami caused serious damage to the Fukushima Daiichi Nuclear Power Plant (NPP) of Tokyo Electric Power Co.(TEPCO). This damage resulted in large amounts of radioactive materials being released into the environment. Since the criticality accident at Tokai-mura of Ibaraki-prefecture in 1999, we have revised the medical response system for radiation emergencies in Japan[2]. However, the accident at the TEPCO Fukushima Daiichi NPP revealed a lot of problems in this system. This article will introduce our system of radiation emergency medicine in Japan and this earthquake and its consequences, and the problems will be discussed.

2. The Great East Japan Earthquake and the accident at TEPCO Fukushima Daiichi NPP

An earthquake measuring 9.0 on the Richter magnitude scale (MJMA = 9.0 according to the Japanese Meteorological Agency) struck the Pacific coast of eastern Japan at 14:46 on March 11, 2011. This earthquake was named The Great East Japan Earthquake. It triggered a tremendous tsunami. Unfortunately, it was then followed by another quake measuring over 7.0 on the Richter magnitude scale almost an hour later, and numerous sustained aftershocks followed. The number of aftershocks measuring more than 5.0 during March 2011 was 427; aftershocks measuring over 7.0, 6.0, and 5.0 were observed at frequencies of 6, 96, and 576, respectively, until December 8 of the same year[3]. The earthquake and tsunami resulted in 15,844 deaths and 3,451 missing (as of December 30, 2011)[4]. The earthquake caused damage to the TEPCO Fukushima Daiichi NPP, located approximately 16 km south-west of its epicenter and 23 km from its hypocenter. This NPP consisted of 6 boiling water reactors (BWR; Units 1 to 6) with a total generating capacity of 4,696 MW.

In terms of the operating status at NPP before the earthquake on March 11, Unit 1 was operating at its rated electric power, Units 2 and 3 were operating at their rated thermal power, and Units 4, 5 and 6 were undergoing periodic inspections. Among them, Unit 4 was undergoing major renovation construction, and all the nuclear fuel in the reactor pressure vessel had already been transferred to the spent fuel pool. Moreover, 6,375 units of spent fuel were stored in the common spent fuel pool. Reactors generate heat after the chain reaction is stopped because of radioactive decay of unstable isotopes and fission products. After shutdown, the temperature of the reactor core is still high over several days before reaching a cold shutdown level. Nuclear fuel rods that have reached a temperature of cold shutdown typically require another several years of water-cooling in a spent fuel pool before they can be safely transferred to dry storage casks. Thus, the cooling system is extremely important. At the time of the earthquake on March 11, the operating Units 1 to 3 automatically shut down at 14:46. Soon after, the emergency generator system came online to control the cooling systems. However, one of the two connections to off-site power for Units 1 to 3 failed due to the earthquake[5]. There were two emergency diesel generators for each of Units 1 to 5 and three for Unit 6[6]. Unfortunately, the earthquake was followed by a huge tsunami (13 to 15 m height) arriving approximately 50 minutes later, which topped the plant's 5.7 m seawall, flooded the basement of the turbine buildings and disabled the emergency diesel generators located there, at approximately 15:41[7]. TEPCO tried to bring batteries and mobile generators to the site. Because of poor road conditions, these could not arrive until 21:00 on March 11, almost six hours after the tsunami struck. As a result, approximately 1.8×10^{16} Bq of cesium-134, 1.5×10^{16} Bq of cesium-137, and 1.6×10^{17} Bq of iodine-131 were released into the atmosphere[8].

3. Medical preparedness and response to radiation emergencies in Japan

3.1. Response system for radiation emergency medicine in Japan

Because of the experience of the JCO criticality accident in 1999, establishing a well-organized response system for radiation emergency medicine has been considered essential. At the end of 2011, Japan had 54 operational nuclear reactors for electricity generation installed in 13 prefectures, and nuclear facilities other than NPP were located in 5 prefectures. Aomori and Ibaraki prefectures had both NPPs and other facilities, and parts of Kyoto, Tottori, and Nagasaki prefectures were included in the emergency-planning zone (EPZ) of such facilities in neighboring prefectures. In this total of 19 prefectures, the radiation emergency medical response system had been established (Fig. 1). In this system, treatment of patients involved in radiation accidents is performed at 3 levels: primary level in hospitals near nuclear facilities; secondary level in local general hospitals; tertiary level by more equipped and advanced hospitals. Primary and secondary facilities have been designated by the local governments of the areas where the nuclear facilities are located, and the National Institute of Radiological Sciences (NIRS) and Hiroshima University Hospital have been designated as

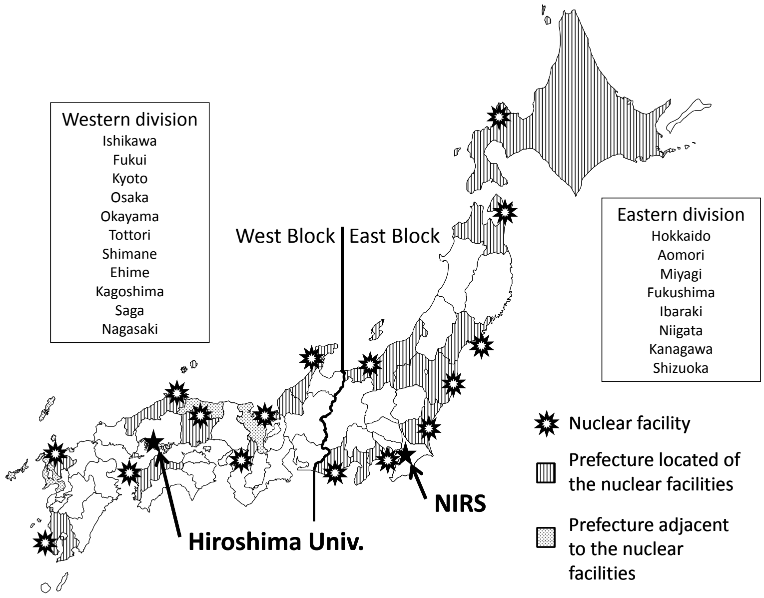

Fig. 1. Medical system for radiation emergency medicine in Japan
Locations of nuclear facilities and hospitals for radiation emergencies are presented. Names of prefectures where nuclear facilities are located or where response systems to radiation emergencies have been established are shown. No nuclear facilities are located in Kyoto, Tottori, and Nagasaki prefectures. However, parts of these prefectures are included in the emergency-planning zone (EPZ) of such facilities in other prefectures and have therefore also established systems for radiation emergencies.

tertiary hospitals in the East and West Blocks of Japan, respectively, by the national government (Fig. 2). Hospitals at the primary level were expected to provide first-aid treatment, primary assessment of contamination with radionuclides, and removal of contamination on the body surface. Therefore, these hospitals had to be equipped with radiation detectors such as survey meters and the minimum requirements for decontamination. Secondary-level hospitals provide medical and radiological triage, decontamination, and treatment of local radiation injuries and whole body exposure, and also initiate treatment for internal contamination. As well as being a tertiary hospital, NIRS has also been designated as the national center of radiation emergency medicine in Japan, providing direct or consultative services to local governments and hospitals as well as to Hiroshima University in the event of an actual radiation incident. Therefore, NIRS is seeking to improve ties with cooperating hospitals in the Radiation Emergency Medical Network Council and to enable cooperation in radiation emergency medicine with external special organizations for receiving patients requiring specialized medical treatment for radiation exposure. Network councils, consisting of experts, have also been established for cytogenetic dose assessments (Chromosome Analysis Network Council) and physical dose assessments (Physical Dosimetry Network Council).

3.2. Education, Training and Exercise/Drill

As part of the efforts for developing personnel for radiation emergency medicine, education, training and drills are important. NIRS has training courses on radiation emergency medicine for professionals involved in radiation emergency medical response, including physicians, nurses, emergency responders and radiation protection personnel. The training course for first responders in radiation emergency provides instruction on basic knowledge and techniques required to rescue victims, administer first aid, and assess body contamination. The training course of radiation emergency medicine for hospital staff provides a general introduction to radiological protection for doctors, nurses, and radiation technologists, and also covers medical care for contaminated and/or heavily exposed patients. Other organizations including Hirosaki and Fukui Universities also hold seminars on preparedness and response to radiation emergency for local government officers, first responders, hospital staffs, and radiation protection officers. However, these seminars are restricted to personnel in the 19 prefectures mentioned above. In Japan, the central and/or local governments perform annual exercises/drills for radiation emergency, and nuclear facility, police, fire departments, hospitals, and other related organizations and agencies are involved. Moreover, hospitals designated as primary or secondary radiation emergency facilities perform in-house exercises.

3.3. Radiation Emergency Medical Assistance Team (REMAT)

In January 2010, NIRS established the Radiation Emergency Medical Assistance Team (REMAT®) to support primary medical care in case of accidents of radiation exposure or contamination with radioactive materials overseas. The team consists of physicians, nurses, radiation

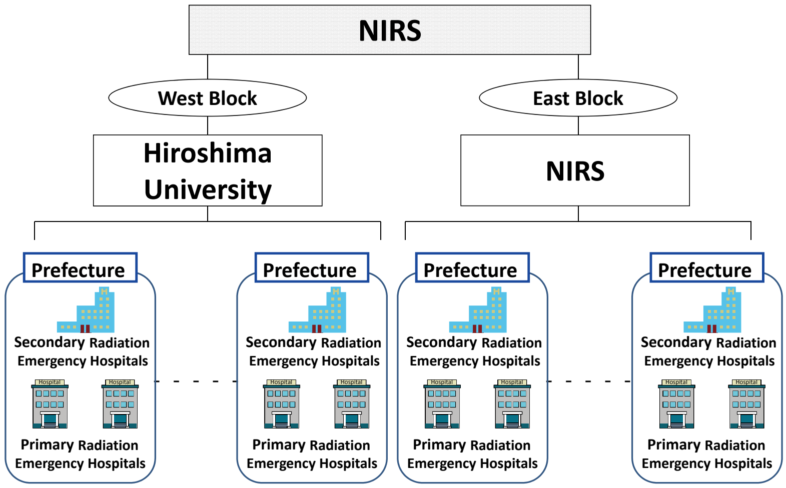

Fig. 2. Hospitals for radiation emergency medicine in Japan
Treatment for radiation exposure is performed at 3 levels in Japan. The National Institute of Radiological Sciences (NIRS) and Hiroshima University Hospital work at a tertiary level in the East and West blocks of Japan, respectively. NIRS is also responsible for both blocks as a national center for radiation emergency medical preparedness. Primary- and secondary-level hospitals for radiation emergency medicine are the responsibility of prefectures, while the national government is responsible for the tertiary level of radiation emergency medicine.

protection experts, and health physicists ready to respond to radiation emergencies, and the team is equipped with advanced portable radiation measuring instruments and medicines. NIRS was ready to provide international medical assistance for radiation emergencies, based on human resources with experience in this field. However, the first REMAT activity was then undertaken for the TEPCO Fukushima Daiichi NPP accident.

4. Roles of NIRS in response to TEPCO Fukushima Daiichi NPP accident

The Great East Japan Earthquake and tsunami caused enormous damage to the NPP of TEPCO, as describe above. Troubles in the cooling systems led to hydrogen explosions and core melting, resulting in large amounts of radioactive materials being released into the environment. NIRS dispatched REMAT, initially consisting of a physician, a nurse, and a health physicist, to the local headquarters located 5 km from NPP almost 17 hours following the earthquake. At the local headquarters, experts from NIRS performed assessment of contamination with radionuclides and decontamination for first responders. Since then, many experts including physicians, nurses, radiation protection experts, health physicists, and logisticians at NIRS have been sent to Fukushima prefecture. The total number of staff who had been sent to Fukushima reached almost 1200 as of January 2012. Experts at NIRS are still being involved in responses to this nuclear accident including the public issue in Fukushima prefecture. Thus, this nuclear accident has required response of an unprecedented scale and over a lengthy period.

4.1. Patients from the hydrogen explosion on March 14, 2011

A hydrogen explosion occurred at the reactor building of the Unit 3 at 11:01 on March 14, and 7 workers and 4 Japan Self-Defence Forces (JSDF) personnel were injured in this explosion. Four JSDF personnel were brought to the local headquarters; all of them showed heavy contamination on their protective gear. Radiation over 1 mSv/h was detected at 10 cm from the surface. After removal of their protective gear, decontamination and taking a shower, the remaining contamination on the face was observed. One JSDF member was transferred to the Fukushima Medical University Hospital, the secondary emergency hospital in Fukushima prefecture, by ambulance. He was diagnosed with brachial plexus injury. One of the other patients had a contaminated wound on the right thigh and was then transferred to NIRS by JSDF helicopter. At NIRS he was also diagnosed as fracture of lumbar transverse process and internal contamination with radioactive iodine and cesium. Three of the 7 workers were transferred to the Fukushima Medical University Hospital by ambulance early in the morning of March 15, together with a nurse and a radiation protection expert from NIRS, since primary hospitals for radiation emergency were located within the evacuation area or did not function. However, even hospitals located outside of the evacuation area could not receive contaminated patients simply because they were not educated for radiation emergency. The exposed doses of experts who took care of patients with contamination were only a few tens of μSv.

4.2. Activities of temporary house-visit operation

The evacuees, who had lived in no-entry zones, areas within a 20-km radius from NPP, had a strong desire to return home temporarily to retrieve their belongings or check on their farms and businesses. Therefore, temporary house-returns of residents were allowed from May 10, 2011. These temporary visits to their homes were limited to 2 - 5 hours to keep radiation exposure to 1 mSv or lower.

Only two persons per household were permitted this visit, and residents under 15 years old and senior citizens were initially not allowed in. In addition, they could not bring out food and farm animals except pets. Later, the residents' vehicles were allowed to be retrieved by the affected owners. To operate these temporary house visits, NIRS was requested by officials at the local headquarters to send a medical experts team including physicians, nurses, and radiation protection experts, to manage the radiation survey and provide medical care at the contamination area in cooperation with Hiroshima and Hirosaki Universities and the National Disaster Medical Center.

4.3. Forward base for battling nuclear disaster at J-Village

TEPCO, its related companies, and JDS were using "J-Village", a soccer training complex, as a forward base for those battling the nuclear disaster. The J-Village is located in the town of Naraha, Fukushima Prefecture, and all the workers going to and from NPP must stop there, receiving radiation checks and decontamination procedures if necessary. In order to reduce the temperature of the reactors at NPP, fire departments of Tokyo, Yokohama, Kawasaki, and Osaka sent emergency units and special fire engines to spray water in and around the complex. NIRS sent radiation protection experts to the J-Village for radiation protection of these firefighters during their operation of spraying seawater, from March 23 through April 2, 2011.

The medical system for radiation emergency in Fukushima prefecture included 6 radiation emergency medical hospitals at a primary level. Due to the earthquake and tsunami, three of these hospitals lost their function. Moreover, the other 3 hospitals were located in the evacuation area within a 20-km radius from NPP. Thus, there was no hospital to receive patients from NPP if an accident occurred or workers became ill. Therefore, patients had to be transported to Fukushima Medical University Hospital located more than 60 km from NPP, regardless of contamination with radionuclides or exposure to radiation. However, this hospital also had damage to lifelines due to the earthquake, nor did it have many staff members well-trained for dealing with contaminated and/or exposed patients. They required support by experts from Nagasaki University. The J-Village also functioned as a primary emergency medical center. The medical team of the local headquarters established this temporary medical center in cooperation with the Japanese Association for Acute Medicine (JAAM). For radiation protection of patients contaminated with radionuclides as well as medical staff, NIRS sent experts of radiation protection to the J-Village from April 10 through August 31.

4.4. Providing information and public communication

Public communication is one of the most important challenges for radiation emergency management, and communicating effectively with the public about radiation effects is a key to its success. There are many communication channels, such as TV, radio, newspapers, websites, hot lines, leaflets, and public meetings. NIRS has provided various, scientifically correct information about radiation and health issues through our website. Many people accessed the NIRS website, which received more than 10 million hits after March 11, most of them before the end of March. Moreover, NIRS opened telephone consultation access for 24 hours and 7 days to provide accurate information about radiation and health issues to the public, medical professionals, first responders, local government officers, and others. NIRS received more than 15000 calls from the public.

5. Discussion

Radiation accidents requiring treatment rarely occur. As a result, there are few medical professionals with any experience with radiation accidents. Nonetheless, it is on the basis of past experiences that medical care by medical professionals and first response by ambulance and police staff can be carried out. In order to effectively respond to radiation accidents, knowledge about radiation and lessons learned from past accidents are essential. In this article, we introduced the system for radiation emergency medical preparedness in Japan, which was intensively revised after the criticality accident in 1999[2]. However, the recent accident occurring at the TEPCO Fukushima Daiichi NPP uncovered many problems in the medical and public response system.

In Japan, local governments with nuclear facilities such as NPPs run the training system of radiation emergency for medical professionals; this medical response system has been established in 19 prefectures, as mentioned above. On the other hand, there is no such system including education or training in prefectures that have no nuclear facilities. Therefore, there are few medical professionals, first responders and local government officers who are able to care for patients involved in radiation emergencies in these prefectures. Since only a few hospitals have been designated as radiation emergency facilities even in prefectures with nuclear facilities, the non-designated hospitals have no capability for receiving exposed and/or contaminated patients. This means that there is limited capability for medical care for patients exposed to radiation and/or contaminated with radionuclides in Japan. In this disaster, primary- and secondary-level hospitals lost their function due to the earthquake and tsunami or evacuation. Further, hospitals without the designation also could not receive patients from NPP, since basic knowledge of radiation and radiation emergency medicine was lacking. Of course, education and training are critical for physicians, nurses, radiation technologists, and first responders who might be involved in case of a radiation emergency medical response. However, this accident has clearly revealed the need for all medical professionals to have basic knowledge of radiation exposure and contamination with radionuclides, since potential sources for exposure accidents can be found anywhere.

One of the most important lessons learned from past accidents is that misunderstandings and misconceptions cause excess anxiety, leading to psychological consequences. Radiation accidents can cause medical, environmental, psychological, and economic problems. Scientifically correct information about health issues is key for the prevention of psychological consequences, and explanation of radiation risks and any countermeasures in plain language is a vital part of an effective risk communication process for not only the general public but also for emergency responders[9]. However, radiation cannot be seen, heard, or felt, and knowledge of radiation exposure is not imparted in schools. There are many "experts" concerning radiation exposure, and they provide differing information. Members of the general public do not understand which information is right or wrong, leading to confusion. In this regard, some patients at hospitals refuse medical tests using X-ray, for the simple reason that radiation increases the risk of cancer mortality. It is vital that correct information about radiation exposure be disseminated before accidents occur. Otherwise, the effects of education would be diminished. The dose of radiation exposure cannot be reduced after the accident has occurred. On the other hand, psychological and economic problems could be prevented or at least minimized. At the very least, we have learned from the accident that accurate risk communication concerning radiation exposure is absolutely essential.

Central and/or local governments have performed an annual radiation emergency drill in Japan. However, drills using the scenario of a radiation/nuclear event caused by an earthquake have never been performed in Japan. This earthquake caused not only death and life-threatening injuries, but also had a tremendous impact on the infrastructures of the public and NPP. The complexity of disasters including damage to nuclear or radiation facilities, particularly in the case of earthquakes, has increased the need for multidisciplinary medical experts as critical assets in disaster responses. We have also learned from this earthquake that there is urgent need for an all-hazards approach, including a "combined disaster" strategy, which should be emphasized for current disaster planning and response.

Acknowledgments

The Nuclear Safety Commission of the Japanese Government is now revising the response system for radiation emergency. This article was written at the end of 2011. Therefore, the system may be changed. We are grateful to our colleagues for their cooperation in the response to the accident at TEPCO Fukushima Daiichi NPP.

References

1. REAC/TS Managing Radiation Emergencies: Guidance for Hospital Medical Management, Oakridge, TN, http://orise.orau.gov/reacts/guide/care.htm.
2. Akashi M, Hirama T, Tanosaki S, Kuroiwa N, Nakagawa K, Tuji H, Kato H, Yamada S, Kamata T, Kinugasa T, Ariga H, Maekawa K, Suzuki G,Tujii H. Initial symptoms of acute radiation syndrome in the JCO criticality accident in Tokai-mura. J Radiat Res Sep;42 Suppl:S 157-166, 2001
3. Japan Meteorological Agency, The 2011 off the Pacific coast of Tohoku Earthquake -Portal-, http://www.jma.go.jp/jma/en/2011_Earthquake.html.
4. National Police Agency of Japan, Damage Situation and Police Countermeasures associated with 2011Tohoku district - off the Pacific Ocean Earthquake, http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf.
5. TEPCO press release, Occurrence of a Specific Incident Stipulated in Article 15, Clause 1 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (Fukushima Daiichi), http://www.tepco.co.jp/en/press/corp-com/release/11031103-e.html.
6. Nuclear and Industrial Safety Agency, The 2011 off the Pacific coast of Tohoku Pacific Earthquake and the seismic damage to the NPPs, http://www.nisa.meti.go.jp/english/files/en20110406-1-1.pdf.
7. TEPCO press release, Overview of the Earthquake & Tsunami and Nuclear Accident, http://www.tepco.co.jp/en/nu/fukushima-np/f1/images/f12np-gaiyou_e_1.pdf
8. Nuclear Emergency Response Headquarters and Government of Japan, Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations -, http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html.
9. Akashi M, Kumagaya K, Kondo H, Hirose Y. Concerns of disaster medical assistance team (DMAT) members about troubles at the nuclear power plant: Experience from the Niigata Chuetsu-oki earthquake, 16 July 2007, in Japan. *Health Phys.* 98:804-809 (2010).