**Topics: Lessons learned on public health from the Fukushima Daiichi Nuclear Power Plant accident**

## < Review >

# Tokyo Electric Power Company Fukushima Dai-ichi Nuclear Power Plant accident and public health

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**Abstract**

Off the Pacific coast of Tohoku Earthquake and subsequent Fukushima nuclear accident attacked Japan on March 11, 2011. The complex disaster with an earthquake, tsunami and nuclear disaster severely damaged and destroyed human life, properties, natural resources and the environment. Mandatory evacuation was ordered after the accident, and loss of the cooling system for safety of the public from the nuclear reactor in the Fukushima Dai-ichi Nuclear Power Plant. This order disturbed the usual daily life of the Fukushima residents and caused an inconvenient situation for a long-time due to the lack of a link to their local community. We tried to discuss various issues regarding the public health activities in response to the Fukushima disaster in this special issue as follows.

Countermeasures: 1) emergency response to the natural disaster, to mitigate the radiation exposure due to the nuclear accident, 2) medium- to long-term support for secondary health risks and 3) educational activities of radiation health risks on humans and care of mental health issues due to anxiety of radiation exposure. All were implemented by various efforts with the cooperation among national and local politicians, residents, suppliers, distributors and so on. The World Health Organization (WHO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Atomic Energy Agency (IAEA) consulted on the response to the Fukushima situations. Although the Fukushima accident was the second worst nuclear accident in the history of nuclear power generation, radiation doses are limited among Fukushima residents and emergency responders who were apparently not exposed to radiation doses higher than the threshold for induction of acute radiation syndromes. In order to control food contamination, provisional regulation values (PRV) were set during radiological emergency situations. Food monitoring and restriction were conducted to protect internal radiation exposure from contaminated food. The Fukushima Health Management Survey was carried out to take care of and to support the health of the Fukushima residents. As a part of this survey, some issues regarding thyroid monitoring and a medium- to long-term secondary health risks still remained. Furthermore, we mention disaster management laws and systems, and the role of the emergency management cycle according to each phase.

With all these matters in mind, we overview the Fukushima accident as a brief introduction to this special issue.

***keywords***: Fukushima Dai-ichi Nuclear Power Plant accident, radiation protection, public health, disaster countermeasures

(accepted for publication, 15th January 2018)

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## I. Overview of the Fukushima Nuclear accident

### 1. A complex disaster with an earthquake, tsunami, and nuclear power plant accident

A severe natural disaster (Off the Pacific coast of Tohoku Earthquake) occurred in Japan on March 11, 2011. Following the magnitude-9.0 earthquake, damaging tsunami waves struck the Pacific coast of Japan including the Fukushima nuclear power plant (FNPP). As a result of this complex disaster with an earthquake, tsunami, and nuclear accident, we lost precious human lives (15,894 people and 2,546 people missing) [1]. In the event of a release of radioactive materials into the atmosphere from a damaged nuclear power plant, radionuclides may be widely dispersed leading to contamination of a variety of materials in the environment (Figure 1) [2]. Human bodies may be exposed to radioactive elements via two major routes. One is “External exposure” which is exposure to radiation released by radioactive materials from outside of the body. The other is “Internal exposure” which is exposure through the intake of air, water, food, and other substances containing radioactive materials into the body by inhalation, oral intake, dermal absorption, and wound penetration. A radioactive plume contains radioactive noble gases and particles, such as Iodine-131 (I-131) and Cesium-137 (Cs-137) [3]. The radioactive noble gas (krypton and xenon) did not fall on the ground but incorporated into human body via inhalation. On the other hand, I-131 and Cs-137 particles fell out onto the ground surface, leading to environmental contamination and external exposure to humans in the track of the radioactive plumes. Furthermore, these radioactive materials may contaminate water and various foods via the food chain. In the Chernobyl accident, no action on restricting contaminated foods was imposed in the early period. Highly radioactive internal exposure was found among children who drank contaminated milk with I-131. The World Health Organization (WHO) reported that there were about 6,000 cases of thyroid cancer, including 20 fatal cases due to internal exposure of iodine at 20 years after this accident [4]. Based on these experiences, food and drinking water monitoring and supply protection actions were taken immediately after the Fukushima accident.

### 2. Dose rate change following the accident

Figure 2 shows the chronological changes in environmental radiation dose rates in Fukushima, Iwaki, and Tokyo. A tremendous amount of radioactive material was mainly discharged into the air from March 12 to March 15, 2011. The Nuclear and Industrial Safety Agency of Japan (NISA) reported that $1.6 \times 10^{17}$Bq of I-131 and $1.5 \times 10^{16}$Bq of Cs-137 were released into the environment during the Fukushima event [3]. They spread to the southwest and northwest directions from the FNPP according to the monitoring data of air dose rates [2]. Air dose rates suddenly increased about 20 $\mu$Sv/h following the Fukushima accident and peaked in mid-march in Fukushima-city located on about 60km north-west from the FNPP. Thereafter, it gradually decreased. On the other hand, in Iwaki city located on 43 km south-west and nearer than Fukushima

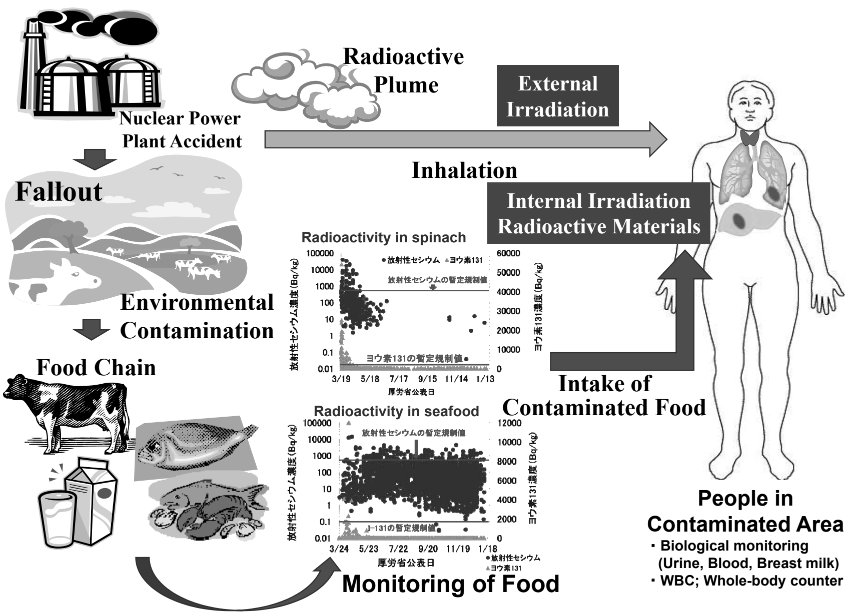


**Fig. 1 Situation of radioactive substances in the environment and health risk after nuclear disaster**

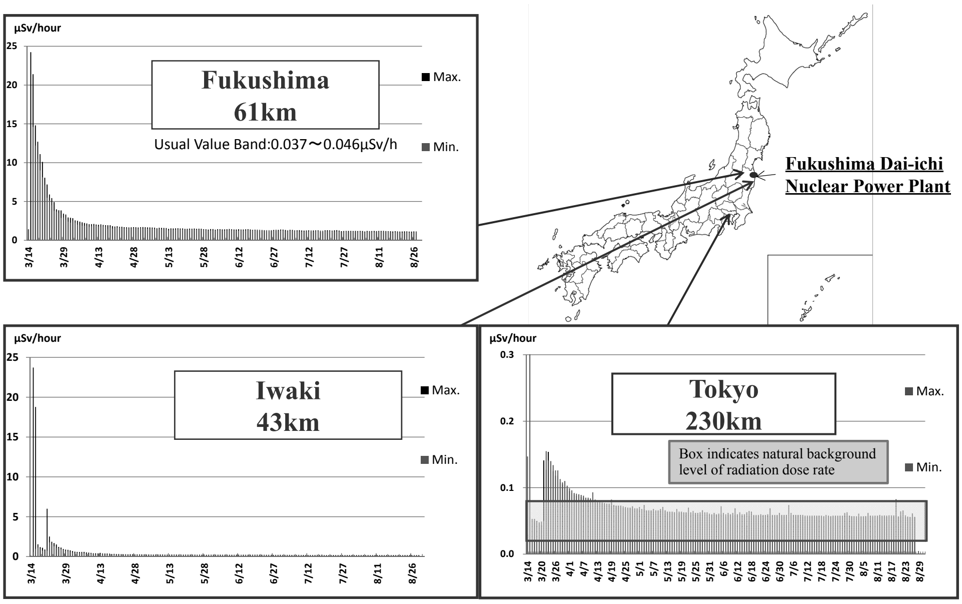


**Fig. 2 Chronological changes in environmental radiation dose rates**

city, the dose rate was lower than that in Fukushima city because of the lower concentration of contaminated soil. Thus, air dose rate is proportional to the contamination levels of soil. Radiation dose rate in Tokyo in March 2011 was slightly increased compared to that before the accident, which is indicated on box in Figure 2. After the middle of April 2011, the dose rate was restored to a background level in Tokyo.

## II. Governmental actions in response to the nuclear disaster

### 1. Countermeasures for Fukushima nuclear power plant (FNPP) accident

Countermeasures for FNPP accident have been arranged by the time course after the declaration of a nuclear emergency situation. The cabinet response office was immediately established after the earthquake. The Ministry of Health, Labour and Welfare (MHLW) issued an order to stand by to the Disaster Medical Assistance teams (DMAT). Japan declared a nuclear emergency after the failure of the cooling system at the damaged reactors at 19:03 on March 11. The Japanese government issued an evacuation order to the inhabitants around the nuclear power plant. The radius of the evacuation zone extended from 3 km to 20 km within about 24 hours after the breakout of the reactor accident and the number of evacuees eventually reached 177,000 (Figure 3). During evacuation, many efforts were conducted to survey residents and monitor radionuclide levels in the atmosphere, foods, farmland, and water. Unfortunately, a serious concern about the evacuation of hospitalized patients was reported [5,6]. Some elderly hospital patients died during their transportation. Details were well documented in this special issue by Tsubokura [7].

The Central Nuclear Emergency Response Headquarters (NERHQ) instructed that stable iodine (potassium iodine:KI) should be administered to the evacuees younger than 40 years old on March 16 to protect the thyroid from radioiodine uptake by the Nuclear Safety Commission. In fact, this order did not fully reach most of the local governments and most people in the affected area did not take KI due to the disordered situation of the complex disaster. Yasui has clearly summarized governmental action for emergency workers in response to the nuclear disaster in the book and this issue [8,9].

### 2. The impact of food contamination due to the Fukushima Accident

In order to mitigate internal radiation exposure due to intake of contaminated food, MHLW made an effort to control the food supply. Terada described provisional regulation values (PRVs) in food and explained the impact of food contamination in the Fukushima accident by using food monitoring data [10]. PRVs are set based on past disasters including Chernobyl nuclear power plant and others [11]. Food with radioactivity levels exceeding these values should not be consumed and distributed in the market. The figures on the PRVs are based on 50 mSv/year of thyroid equivalent dose for radioactive iodine, and on 5 mSv/year of the effective dose for radioactive cesium [12]. These PRVs are set very conservatively. There should be no health concerns even if some food was consumed for a brief period

| Date | Public health measures |
|---|---|
| 11-Mar PM2:46 | The earthquake occurred |
| 11-Mar PM2:50 | The Cabinet Response Office was established |
| 11-Mar PM3:04 | MHLW issued an order to stand by to the DMAT |
| 11-Mar PM3:14 | The Headquarters for Emergency Disaster Control of government was established |
| 11-Mar PM7:03 | Declaration of a nuclear emergency situation |
| 11-Mar PM9:23 | Evacuation of residents: 3km radius from NPP |
| 12-Mar AM5:44 | Evacuation of residents: 10km radius from NPP |
| 12-Mar PM6:25 | Evacuation of residents: 20km radius from NPP |
| 13-Mar | Start radioactivity surveillance |
| 15-Mar | Indoor evacuations: within 20 to 30km from NPP<br>Medical transport: within 20 to 30km from NPP |
| 16-Mar | KI administration |
| 18-Mar | Health counseling |
| 21-Mar | Completed medical transport: 700 in patients (6 hospitals) |

MHLW: Ministry of Health, Labour and Welfare
DMAT: Disaster Medical Assistance Team
NPP: Fukushima Dai-ichi Nuclear Power Plant

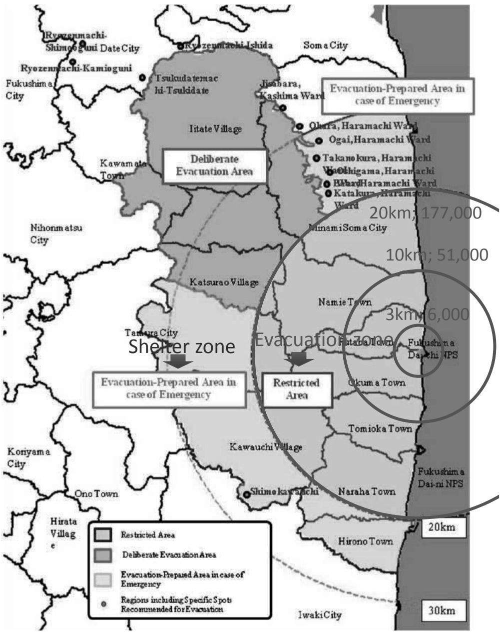


**Fig. 3 Initial actions following the Fukushima Dai-ichi Nuclear Power Plant accident**

before the ban was implemented. The MHLW collates the results of testing and emergency monitoring conducted by the local governments on radioactive materials in food and publishes these results on the website (http://www.mhlw.go.jp/english/topics/2011eq/index_food_radioactive.html).

We are always exposed to natural radiation including cosmic rays from outer space; terrestrial radiation from natural radioactive materials in the ground; ingested radioactivity, principally potassium-40 and polonium-210 in foods; and inhaled radioactivity, mainly radon. So, the global average annual effective dose from natural background is 2.4 mSv [13]. In Japan, the average annual effective dose is lower than the global average, at around 2.1 mSv [14]. According to surveillance data of foodstuff after the Fukushima accident, the median total committed effective dose was estimated to be 0.1 mSv [12]. Fortunately, internal exposures from the contaminated food due to the Fukushima accident were small (Figure 4).

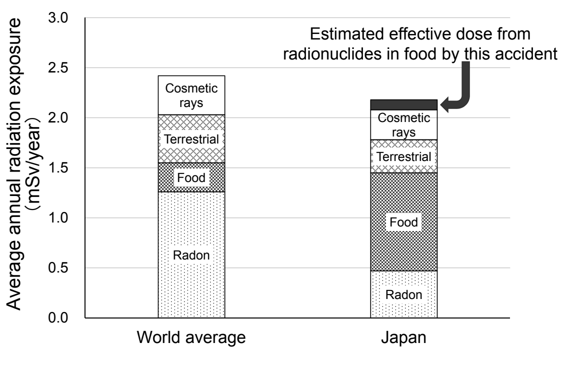


**Fig. 4 Natural background radiation and estimated effective dose from radionuclides in food by this accident**

### 3. Thyroid monitoring for children

The risk of thyroid cancer by taking in radioiodine released from the Fukushima accident was the major concern for the public in the early stage, because we know that there was an increase in pediatric thyroid cancer after the Chernobyl accident [15-17]. The Local Nuclear Emergency Response Headquarters performed a simplified survey for thyroid internal exposure in Iwaki City, Kawamata Town and Iitate Village from March 24 to 30 in 2011 on 1,149 children. The survey results of all of the people except 66 people, for whom results of the survey were unable to be generated appropriately due to a higher background, were below 0.2 $\mu$Sv/h as a screening level, which thyroid equivalent dose to 100 mSv for one-year-old children [18,19]. Takahashi discussed this important issue regarding thyroid monitoring during childhood [20].

### 4. Survey of mother's milk

Since many mothers were worried about breastfeeding to grow their infants, the MHLW planned to measure radioactive concentrations in mother's milk. We measured I-131 levels in 126 breast milk samples from 119 volunteer lactating women residing within 250 km of the FNPP, between April 24 and May 31, 2011. Seven of the 23 women who were tested in April secreted a detectable level of I-131 in their breast milk [21]. Furthermore, Cs-134 and Cs-137 contents were determined in 10 placentas from 10 women who gave birth to term singleton infants during the period between October 2011 and August 2012 using high-purity germanium detectors for gamma ray spectrometry [22]. Degree of contamination of the placenta with radioactive Cs was lower even in women who resided within 50 km of FNPP compared to Japanese and Canadian placentas in the mid-1960s after repeated nuclear tests and in northern Italian placentas from 1986–1987 after the Chernobyl power plant accident. Actually, this low concentration of radiocesium will not cause any detectable risk for babies, because about 60 Bq/kg of radiopotassium, naturally exists in their bodies. We reached the following conclusions based on this survey: 1) Measures are being taken to deal with radioactive materials, with evacuation orders and food intake restrictions being issued, so even if radioactive materials from the air, water, or food intake pass into breast milk, it is thought that this will not affect the health of infants. 2) Since breast milk is nutritious and has other advantages, breast-feeding mothers are advised not to worry too much. There is no problem with continuing to lead normal lives. Mothers with their breast milk containing some radioactive materials were reexamined later, and no radioactive materials except natural radioactive materials were found in the breast milk during the 2nd test.

## III. Dose estimation and assessments of health risks due to the Fukushima accident by International Organizations

Initially, WHO conservatively assessed health risks of residents due to radiation exposure of the FNPP by September 2011 in the first one year after the Fukushima accident in order to avoid underestimation of radiation risks. This report concluded that increases in diseases due to radiation released as a result of the latest nuclear accident is undetectable, and risk increases are ignorable in Japan except for some areas in Fukushima Prefecture, as well as in neighboring counties [23]. UNSCEAR tried to assess health risks as realistically as possible by taking the accumulation of scientific knowledge into consideration in the second year after the accident. UNSCEAR says that radiation doses are small and it is hardly likely to identify any health effects of radiation among the Japanese people in the future [24]. However, both reports still contain uncertainties regarding dose assessment due to the limitations in actual data. UNSCERA continues to revise the assessment when sufficient information was obtained [25,26].

## IV. Risk communication

Risk communication is considered an important issue not only in the emergency phases but also in the recovery phases [27]. In this issue, Shineha points out the perturbation of relationship between the government and public by the power of social media during the early emergency situation. He focused on science communication which was not solely examining the scientific contents, but also the social contexts of science and technology [28]. Yamaguchi also introduced the good practice of the establishment of local community engagement in Date city [29]. Many efforts have contributed to the smooth actions to resolve various problems. The stakeholder involvement provided a good opportunity for networking to work together in resolving the outstanding communication challenges. Public health nurses are believed to contribute to the support of the health of the local community. They work together with administrative officers and radiation specialist to address problematic issues. In conclusion, we would like to mention the risk communication based on scientific knowledge is significantly important to reduce the sense of resident's uncertainty and fears.

## V. Disaster management laws and systems, and the emergency management cycle

Natural disasters cause a great loss of people's lives and properties in Japan every year. In order to protect national land and the public, disaster management laws and systems were developed for promoting national land conservation and progressing society's capabilities (Figure 5) [30]. The disaster management system has been continuously reviewed and revised following the lessons learned from large-scale disasters. Initially, the Disaster Relief Act was implemented at 1947 after the Nankai earthquake to protect disaster affected people and maintain social order by the national government in cooperation with local public corporations, the Japan Red-Cross and other organizations, and the general public, at the time of disaster, by providing emergency relief. The cost for emergency response to assist the affected people is subjected to the local and national governments. The Disaster Countermeasures Basic Act has constantly been reviewed and amended since its first enactment in 1961. This act provides the basic idea of disaster countermeasures including organization of disaster management administration, and planning system: development and promotion of systematic disaster management measures, promotion of disaster countermeasures, protection of affected people and their livelihood, financial measures, and state of

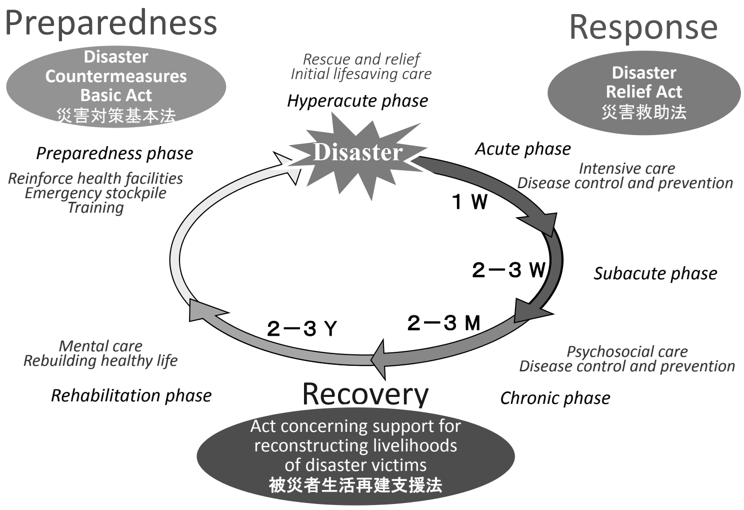


**Fig. 5 Medical response at each phase of the disaster cycle**

disaster emergency. The Act concerning the support for reconstructing livelihoods of disaster victims was enacted in 1998 following the Great Hanshin-Awaji Earthquake. The Headquarters for Reconstruction of the Hanshin-Awaji Area (headed by the Prime Minister) was established to conduct reconstruction in disaster affected areas in a planned manner; to rebuild disaster victim's abilities to live autonomously; to provide disaster-affected people with shelter, and to revitalize the local economy.

Health crisis management is responsible for the hazardous environments and health, and strengthening public health emergency response. Emergency management response is considered to be divided into three phases: response, recovery, and preparedness (Figure 5). In the event of a disaster (acute emergency response phase), disaster and damage information is quickly collected and shared by secure communications to carry out effective emergency activities such as emergency rescue and medical operations. The Disaster Medical Assistance Teams (DMATs) are dispatched to provide wide-area medical services. These teams transport severely injured persons via Self-Defense Forces vehicles and aircrafts to hospitals outside the disaster stricken zone. In recovering and reconstructing from disasters (recovery phase), the aim is not merely to restore public buildings to their original state. In order to improve the disaster resilience of the community and to reduce disaster damages, there must be close cooperation among stakeholders such as residents, politicians, scientists and workers, to build momentum for a nationwide movement. In particular, public health workers collaborated with volunteers and helped to identify health problems among affected people. In the preparedness phase, the Basic Disaster Management Plan is a comprehensive and long-term disaster management plan forming a foundation for the Disaster Management Operations Plan and Local Disaster Management Plan Disaster Countermeasures. A Disaster Management System is established against various disasters such as an earthquake, tsunami, land-slide, large-scale floods, volcano, and blizzard. Essential actions to prepare for the future disaster are disaster reduction drills and exercises, and human resources development for local public officers who are engaged in services for disaster management. There are links among each phase which we described above. Emergency management forms a cycle, rather than a linear pathway, performing the same process over again from the beginning at the end of each go-round.

## Acknowledgements

The authors would like to thank Prof. Erik Robert Svendsen, PhD, Department of Public Health Sciences, Medical University of South Carolina for English editing and careful review of the manuscript. This work was supported by Industrial Disease Clinical Research Grants (#150803-02) from the Japanese Ministry of Health, Labour, and Welfare.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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## 東京電力福島第一原子力発電所事故と公衆衛生

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**抄録**

日本では，2011年３月11日に発生した東日本大震災に伴う東京電力福島第一原子力発電所事故により，地震，津波，原発事故という未曾有の複合災害を経験した。事故直後より強制的な避難が強いられ，自治体のつながりがなくなるなど非常に困難な日々が続いている現実も残されている。本特集では，これらの課題に公衆衛生の視点で幅広く議論することを試みた。

事故後は，行政機関，自治体，住民，生産者，流通業者等様々な立場の人々の努力により，１）甚大な自然災害に対する対応，および原発事故に伴う被ばく線量軽減の対応，２）中長期的な二次的な健康影響を防ぐための対応，３）放射線・放射能に対する理解，不安軽減対策等が実施されてきた。

WHO, UNSCEAR, IAEA等国際機関等からの多くの報告書が出され，放射性影響は限定的であると評価されている。原発事故は，チェルノブイリ原子力発電所事故に次ぐ，非常に大規模なものであったが，幸いにして原発サイト内の緊急作業従事者を含め，一般公衆住民の方々にも，被ばく線量は限定的な範囲にコントロールされ，被ばくによる急性放射線症候群を発症するような事例は無かった。事故後に，住民の内部被ばくを防護するために飲食品の放射性物質に関する暫定基準値が設定され広範なモニタリングも開始された。福島県では事故に伴う県民の健康の見守りと将来にわたる健康増進を目的に県民健康調査が実施されている。調査の一部である「詳細調査」で実施されている，甲状腺検査の結果や，避難等に伴う中長期的な二次的な健康影響についても課題が残されている。合わせて，国内における災害対策関係法規と災害時の各フェーズの保健医療の役割を概説する。これらも踏まえ，事故の概要を紹介し，本特集記事全体の導入を行う。

**キーワード**：東京電力福島第一原子力発電所事故，放射線防護，公衆衛生，災害対策