

A Review of the Fukushima Nuclear Reactor Accident: Radiation Effects on the Thyroid and Strategies for Prevention

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Abbreviations:

Tokyo Electric Power Company (TEPCO); Becquerel (Bq); cesium 134 (Cs-134); cesium 137 (Cs-137); Fukushima Daiichi Nuclear Power Stations (FDNPS); iodine-131 (I-131); microsievert (μ Sv); United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR); whole body counter (WBC)

Abstract:

Purpose of review: This is a summary of the nuclear accident at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Stations (FDNPS) on March 11, 2011 to be used as a review of the radiation effects to the thyroid and strategies of prevention.

Recent findings: The amount of radioiodine released to the environment following the Fukushima accident was 120 Peta Becquerel, which is approximately one-tenth of that in the Chernobyl accident. Residents near the FDNPS were evacuated within a few days and foodstuffs were controlled within one or two weeks. Therefore, thyroid radiation doses were less than 100 mSv (intervention levels for stable iodine administration) in the majority of children, including < one year-old, living in the evacuation areas. Because the incidence of childhood thyroid cancer increased in those residing near the site following the Chernobyl accident, thyroid screening of all children (0-18 years old) in the Fukushima Prefecture was started. To date, screening of more than 280,000 children has resulted in the diagnosis of thyroid cancer in 90 children (approximate incidence, 313/million). Thus, although the dose of radiation was much lower, the incidence of thyroid cancer appears to be much higher than that following the Chernobyl accident.

Summary: A comparison of the thyroidal consequences following the Fukushima and Chernobyl nuclear reactor accidents is discussed. We also summarize the recent increased incidence in thyroid cancer in the Fukushima area following the accident in relation to increased thyroid ultrasound screening and the use of advanced ultrasound techniques.

Introduction:

A nuclear accident at the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi Nuclear Power Stations (FDNPS) occurred on March 11, 2011. Although the amount of radioiodine (I-131) released in Fukushima was about one-tenth of that following the Chernobyl nuclear accident in 1986, there was significant public concern regarding potential adverse thyroidal consequences, particularly the possibility of an increased incidence of childhood thyroid cancer. In this review, we provide a summary of the accident, strategies employed to decrease exposure to radioactive iodine, the dose of radiation to the thyroid, an estimate of risk of thyroid cancer from the radiation dose, the most recent results of population-level thyroid ultrasound screening, and how future healthcare initiatives in Fukushima might be impacted following this accident.

OUTLINE OF THE ACCIDENT AND SUBSEQUENT ACTIONS TAKEN TO DECREASE RADIATION EXPOSURE

Fukushima nuclear reactor accident

A 9.0 Richter-scale earthquake and resulting tsunami occurred at 14:46 on 11 March 2011, the largest in Japan's recorded history. The earthquake and tsunami triggered a nuclear reactor accident of the Fukushima Daiichi Nuclear Power Stations (FDNPS) [1,2]. At 14:46, the operational FDNPS was automatically shut down. All six external power supply sources malfunctioned following the earthquake, and emergency diesel power generators were started. However, at 15:37, the tsunami struck the emergency diesel generators and its distribution boards, thus resulting in loss of all power supplies. The nuclear fuel in each core, although not covered by water, was exposed, thereby leading to a core melt.

These events resulted in a large amount of radionuclide released into the atmosphere. The estimated total release assumed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) for iodine-131 (I-131), cesium-134 (Cs-134) and cesium-137 (Cs-137) were 120, 9.0 and 8.8 Peta Becquerels (PBq) [3**], respectively. Figure 1A shows the results of airborne monitoring by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the United States Department of Energy (DOE), as expressed in microsievert (μSv)/hour at 1 meter from the ground on 29 April 2011 [4,5].

Protective actions following the Fukushima accident

At 20:50 on 11 March 2011, the Governor of Fukushima Prefecture issued instructions for the evacuation of settlements within 2 km of the FDNPS. At 21:23, the Director-General of the Nuclear Emergency Response Headquarters (Prime Minister) ordered the evacuation of individuals within 3 km of the FDNPS and for all individuals within 10 km to remain sheltered indoors. At 18:25 of the same day, the evacuation radius was expanded to 20 km. On 15 March 2011, instructions were issued ordering all people living between 20 km and 30 km from the FDNPS to shelter indoors [1-3**].

On 16 March 2011, Japanese and prefectural governments began to monitor select foodstuffs (milk, vegetables, grains, meat, fish, and others). Foods containing radioactive material that exceeded the provisional regulation values, as recommended on 17 March 2011 by the Ministry of Health, Labour and Welfare (MHLW) of Japan, were prohibited from distribution on 21 March 2011 and from consumption on 23 March 2011 [1-3**].

On 22 April 2011, “deliberate evacuation areas” were established for specific areas beyond the 20-km zone where the effective dose might exceed 20mSv within a year [1-3**]. Most

residents of these areas were then evacuated between April and June 2011. Figure 1B shows the distribution of these areas [3**, 4]

RADIATION DOSE TO HUMANS?

Numerous estimations of the radiation dose to exposed individuals have been summarized in reports from the World Health Organization (WHO) [6] and UNSCEAR [3**]. In the present review, the results of measured and estimated individual doses are proposed from data gathered 3 years following the accident.

External radiation exposure in the initial 4 months following the accident

The Fukushima Health Survey reports the estimated external radiation dose emitted to exposed residents, based on descriptions of self-reported behaviour following the accident [7]. The National Institute of Radiological Sciences (NIRS) had developed external dose estimations for Fukushima residents [8*], and this system was adopted in the Fukushima Health Survey. The external effective dose between March 12 and July 11, 2011 is estimated by superimposing the individual behaviour data of each day on the respective daily dose rate map. Behaviour data were obtained regarding the description of the location individuals lived at following the nuclear accident, type of location/building, duration spent at the location, duration spent outdoors, and the actual times of trips between indoor and outdoor locations.

These results have been reported on the Japanese-language website of the Fukushima Prefecture, with the most recent report summarizing all available data until 31 Dec 2013. Among 2,056,994 residents in the Fukushima Prefecture, data were obtained from 515,212 (25.0%, not including radiation workers) individuals for analysis. The external effective dose between March 12 and July 11 in 2011 was estimated to be <1 mSv in 66.3% of individuals, <2

mSv in 94.9%, <4 mSv in 99.6%, < 5mSv in 99.8%,; 12 subjects showed doses >15 mSv. The highest dose was 25mSv from the collected data, which included residents in the areas recommended for evacuation [9].

External radiation exposure as reported by personal dosimeters

Measured individual external doses of the Fukushima residents, as obtained from personal dosimeter readings, are summarized in a recent report [10*]. The reported data include the type of personal dosimeter and its sensitivity, measurement period, number and age of residents surveyed, and dose range by different summary reports. The Fukushima Prefecture recently announced the results of these measurements in its 22 municipalities ; the median reported values were <1 mSv/year [11].

Internal radiation from radioactive cesium as measured by whole body counter (WBC)

The Fukushima Prefecture has reported the results of internal radiation doses measured from June 2011 to February 2014 in 184,208 individuals, including those of the Fukushima Prefecture residents, as well as evacuees in the Niigata Prefecture. Of these, 184,182 (99.9%) showed values of a committed effective dose (a measure of health effects to an individual following intake of radioactive material) that were <1 mSv; the maximum dose was 3mSv in two people [12]. A portion of these reports are published in English [13].

Hayano et al. reported that, for the period from October 2011 to February 2012, the presence of Cs-134 and Cs-137 in the body could be detected in 12% of the 33,000 residents of the Fukushima Prefecture and neighbouring prefectures, which later decreased to 1% [14].

Tsubokura et al. evaluated the Cs-134 body burdens of 1,432 children and 8,066 adults by WBC in Minamisoma City, which is located 23 km from the FDNPS, for the period from September

2011 to March 2012, and reported that radioactive cesium was detected in 16.4% of children (median, 11.9 Bq/kg) and in 37.8% in adults (median, 11.4 Bq/kg) [15]. Committed effective doses were >1 mSv in all but 1 resident (1.07 mSv). However, in these few months, cesium was detected in less than 1% of children.

THYROID RADIATION DOSE

Direct measurements only indicate the internal exposures from the radionuclides present in an individual at the time of monitoring. However, the reported direct measurements covered only a limited number of people and locations and might be insufficient to accurately estimate the internal exposure of most people in Fukushima [3* *]. In contrast, the indirect measurements, as obtained by modelling, are often decreased by the ingestion of dietary seaweed on the order of one-fifth or one-tenth. For example, thyroidal uptake of I-131 at 24 hours decreased to less than 5% following ingestion of a cup of seaweed, such as Konbu soup [16]. Any model to estimate thyroid radiation dose by an assumption of thyroidal iodine uptake is affected by iodine exposure (i.e. the ingestion of seaweed), which is almost impossible to quantitatively assess in the initial several months following a nuclear accident. Therefore, the direct measurements of thyroid radiation dose are those summarized in this review.

Thyroid radiation dose as determined by a NaI (TI) scintillation survey meter

The System for the Prediction of Environmental Emergency Dose Information (SPEEDI) has suggested that the thyroid equivalent dose may have been as high as 100 mSv in hypothetical one-year-old children in some areas, based on the assumption of continuous radioiodine exposure from March 12 to March 24, 2011 [17] (Figure 2A). Thus, it was urgent to evaluate the thyroid dose for residents in these areas.

However, thyroid monitors were left within the evacuation areas and could not be used for the measurements. Due to the unavailability of thyroid monitors, an alternative thyroid-monitoring method, the NaI (TI) scintillation survey meter, was suggested to measure ambient dose rates. These tests were performed from March 26 to March 30, 2011, using a NaI (TI) scintillation survey meter. The screening level was set under the assumption that a reading of 0.2 $\mu\text{Sv/h}$ on the survey meter corresponds to 100mSv in the case of 1-year-old infants, as based on experiments by the NIRS. Using this method, the radiation doses of 1,080 children under the age of 15 were measured in Iwaki City (134 children), Kawamata Town (647) and Iitate Village (299) in the Fukushima Prefecture as recommended by the Nuclear Safety Council (NSC). No children showed a level greater than 0.2 $\mu\text{Sv/h}$ threshold, with the highest level at 0.1 $\mu\text{Sv/h}$. Of these children, 55% showed only background radiation levels or lower, and 99% had levels less than 0.04 $\mu\text{Sv/hr}$ [18]; data were later expressed as mSv. Here the distribution of thyroid equivalent doses was estimated by the results of the screening survey and the intake scenario from March 12, 2011 to the day before measurements. However, it must be noted that values may differ according to the intake scenario, and the intake scenario of only May 15 may double thyroid equivalent doses. Figure 2B shows the distribution of the thyroid equivalent doses in these children [19].

These results were extensively discussed at the Expert Meeting [20] with scientists who performed the measurements in these areas, as this test is the only large-scale direct measurement of thyroid I-131 exposure. The number of children surveyed was not many, but in Kawamata Town and Iitate Village, the studies were obtained in more than 30% of all children in these areas using a non-random method.

Thyroid radiation dose as determined by a NaI (TI) scintillation spectrometer at the neck of examinees and by WBC

The thyroid radiation doses in evacuees from Fukushima were determined by Hirosaki University (Aomori, Japan). The thyroid dose was determined by NaI (TI) scintillation spectrometer at the neck of the examinees during the period from April 12 to 16, 2011. The median thyroid equivalent dose in 62 evacuees was estimated to be 4.2 mSv in children and 3.5 mSv in adults, with maximum values at 23 and 33 mSv, respectively. Five children under the age of 9 and eight under the age of 20 were included [21].

In Nagasaki, the internal radioactivity in evacuees and short-term visitors to Fukushima has been measured by WBC since March 15, 2011. Internal radioactivity was measured in 173 people who stayed in the Fukushima prefecture between March 11 and April 10, 2011. The average length of stay was 4.8 days. I-131, Cs-134 and Cs-137 were detected in more than 30% of examined individuals. The maximum committed effective dose and thyroid equivalent dose were 1 mSv and 20 mSv, respectively [22].

Other measurements of individual thyroid I-131 exposures

Individual thyroid I-131 doses have been reported from several places in a small number of individuals [23-26].

THYROID SCREENING OF ALL CHILDREN IN FUKUSHIMA PREFECTURE

The Fukushima Health Management Survey has been conducting thyroid ultrasound examinations for all children (approximately 360,000 people) aged less than 18 years at the time of the accident in Fukushima Prefecture.

Methods of ultrasound examination

The protocol for ultrasound examination has been summarized in the Fukushima Health Management Survey [7] and the presentation at the Workshop [27]. In brief, thyroid ultrasounds have been performed only using machines which (a) have a 10-MHz or higher frequency probe, (b) is able to save Digital Imaging and Communications in Medicine (DICOM) images, (c) has a color Doppler function, (d) is able to save moving images, and (e) is able to transfer saved data to media. Examiners are required to be a specialist in the relevant medical societies.

When the initial thyroid ultrasound reveals a nodule or cyst, a confirmatory examination is to be carried out at Fukushima Medical University Hospital or another hospital certified by the expert committee for advanced ultrasound examination. During the confirmatory examination, a detailed ultrasound, blood testing, urinalysis, and aspiration biopsy cytology are performed as necessary. Ultrasound devices used in the confirmatory examination must have an 18-MHz or higher frequency probe. Specialists of the Japanese Society of Pathology are required for cytologic diagnosis of these specimens.

Results of the first cycle in the Fukushima Prefecture

The first cycle of examination was started in October 2011, and the primary examination of the first cycle was completed in March 2014. Among the 368,651 subjects (all <18 years old) in the Fukushima Prefecture, 295,511 (80.2%) subjects were screened, of whom 287,056 (97.1%) were followed up with a confirmatory ultrasound examination and cytology obtained as necessary. In these 287,056 subjects, nodules <5.0 mm were found in 1,587 (0.5%), nodules >5.1 mm in 2,051 (0.7%), cysts <20.0 mm in 137,077 (47.8%), and cysts >20.1 mm in 12 (<0.1%).

The results of the cytologic evaluations are shown in Figure 3; of the total sample, 90 were suspicious for malignancy (prevalence, 313/million). Following surgery, 51 had papillary thyroid carcinoma (prevalence, 177/million). The mean tumor size was 14.2 ± 7.4 (5.1-30.3) mm. The average age at the time of surgery was 16.9 ± 2.7 (8-21) years, corresponding to an average of 14.7 ± 2.7 (6-18) years at the time of the nuclear accident (Figure 3) [28].

Thyroid screening in other areas of Japan

Children in three prefectures (Aomori, Nagasaki, and Yamanashi)

In order to compare the Fukushima results against a control population, thyroid ultrasound screening using the same procedures was conducted in 4,365 children aged 3 to 18 years from three Japanese prefectures (Aomori, Nagasaki and Yamanashi) [29*]. Overall, thyroid cysts were identified in 56.88% and thyroid nodules in 1.65% of the participants. Although the prevalence of cysts and nodules varied among the examination areas, no significant differences were observed among the three examination areas in the prevalence of cysts and nodules less than 5 mm. In addition, after the publication of the above results, only one patient with papillary thyroid cancer was found among these 4,365 control subjects screened (prevalence, 230/million) [30].

Students at the age of puberty

In one survey, 9,988 students at Chiba University underwent thyroid screening with palpation by a doctor at an annual physical health check-up, with 119 students found to have suspicious findings. Out of these, 87 had a thyroid ultrasound, and four students were subsequently diagnosed with thyroid cancer. One was a foreign student and 3 were Japanese (prevalence, 300/million); all four students underwent surgery [31].

Results of two other studies were presented at the second meeting on the evaluation of thyroid screening by the board of Fukushima Prefectural Health Survey [32]. At Okayama University, of 2,307 students examined, 3 patients with thyroid cancer were found (prevalence, 1300/million); at Keio High School, of 2,868 female students examined, 1 was found to be thyroid cancer (prevalence, 350/million).

In comparison, according to data from the Japan National Cancer Institute [33], the annual incidence of thyroid cancer is 6.4/million in people from 15 to 19 years old.

COMPARISON BETWEEN CHERNOBYL AND FUKUSHIMA

I-131 emitted dose: The total I-131 released by Fukushima nuclear reactor accident was one-tenth that of the Chernobyl accident [1-3**].

Thyroid radiation dose: Foodstuffs containing radioactive iodine levels that exceeded the provisional regulation value were prohibited from distribution on 17 March 2011 and from consumption on 23 March 2011 [1-3] following the Fukushima accident. In comparison, following the Chernobyl accident, there was no restrictions for ingesting contaminated milk among children [34-36]. Detailed calculation of the thyroid radiation dose in Belarus and Ukraine was finally published in 2011 [37, 38]. A comparison of the thyroid radiation doses between Fukushima and Chernobyl is shown in Figure 4. Thyroid radiation dose in Fukushima is almost at the zero line in the figures of dose relation between radiation dose and risk of thyroid cancer in Belarus and Ukraine.

Incidence and prevalence of childhood thyroid cancer: In Chernobyl, the incidence of childhood thyroid cancer was 1/million from 1986-1988. This began to increase in 1990 and reached a peak of 40/million in Belarus, as assessed as the total number of patients who had surgery of

the total number of children in Belarus [34]. This proportion decreased to 1-2/million after 2002 [35]. In Fukushima, the prevalence of childhood thyroid cancer was 311/million during the first cycle (0-18). The prevalence of thyroid cancer found by ultrasound examination in other areas of Japan did not differ from that in the Fukushima Prefecture. In Figure 4, the ages of children with thyroid cancer at the time of accident are compared between Fukushima and Chernobyl. Many children were <10 years in Chernobyl, while in Fukushima, no children were < 5years old and only a few were < 10years old.

HEALTH IMPLICATIONS FOR THE PUBLIC IN FUKUSHIMA

Adverse acute health effects have not been observed among the workers and the general public that could be attributed to radiation exposure from the accident. The average first-year effective doses to the public were estimated to range from approximately 1 to 10 mSv for adults and about twice this level for 1-year-old children [3**].

The values for individual exposure in this review are much lower than those arrived upon using models by the UNSCEAR. Risk models suggest a small increased risk of cancer for such doses. However, any overall increase in disease incidence in the general population due to radiation exposure from the Fukushima accident would likely be too small to be observed, compared to the lifetime baseline risk for the overall Japanese population [3**].

Thyroid cancer

For 1-year-old infants, average absorbed radioiodine doses to the thyroid were estimated by various models to range up to about 80 mGy [3**]. However, measured values in more than 1,000 children from the evacuation areas were <15 mSv in 99% of children 0-14 years old, with

the maximum dose at 35 mSv [19, 20]. The possibility of a large number of radiation- induced thyroid cancers in the Fukushima Prefecture, such as those which occurred following the Chernobyl accident, is likely low [3**], as absorbed doses to the thyroid after the accident were significantly lower than those after the Chernobyl accident (Figure 4). The incidence of thyroid cancer differs greatly by sex and age (especially in children). A very low incidence of thyroid cancer in children <5 years globally was the major reason supporting the relative increase of thyroid cancer in Chernobyl shortly following the accident [34].

In atomic bomb survivors, the excess relative risk of thyroid cancer at 1 Gy has been estimated as 1.28 at age 60 following acute exposure at age 10]. This risk decreases sharply with increasing age at exposure, with little evidence of increased thyroid cancer rates for those exposed after age 20 [40].

Development of advanced ultrasound techniques for the screening and diagnosis of thyroid cancer is an important reason for its increased incidence worldwide in the recent decades [41]. In fact, one of the most significant differences between the annual incidence rates of thyroid cancer in Chernobyl and Fukushima may be due to ultrasound screening, as the thyroid radiation doses in Fukushima were less than the intervention threshold in the majority of children, even in the areas recommended for evacuation.

FUTURE PLANS FOR SCREENING OF THYROID CANCER IN FUKUSHIMA

Topics regarding the screening effects and subsequent decision analyses on thyroid cancer incidence are not included in this review due to the large scope of these topics; the reader is referred to several excellent references regarding guidelines [42-44], epidemiology and healthcare [45-51], and treatment [52-59] of thyroid cancer.

Despite the low thyroidal radiation dose emitted, screening of thyroid cancer in Fukushima should continue for the purposes of routine monitoring. However, it is important to acknowledge that continued screening may contribute to increased fear, given the increased incidence of thyroid cancer by age, irrespective of radiation exposure. Because of this, it is important to consider the aims of screening before beginning the second cycle and develop a protocol based on these aim. Although a high number of radiation-induced thyroid cancers in the Fukushima Prefecture is unlikely [3], the aim of screening should include obtaining these relevant data. These screening efforts should also be conducted in control populations who were not exposed to radiation to provide valid comparisons. However, human right of such control children has to be carefully considered, and an indication of treatment of so-called over diagnosis of thyroid cancer in control children has to be carefully evaluated.

HEALTH IMPLICATIONS OTHER THAN RADIATION

As described in the UNSCEAR report [3**], the most important health effects observed thus far among the general public and among workers are those related to mental health and social well-being. These relate to the significant impacts of the earthquake, tsunami, and the Fukushima nuclear accident, which include the fear and stigma related to real and perceived health risks associated with ionizing radiation. At the end of the 3rd year, the number of disaster-related deaths (1660) was close to the number of disaster-deaths (1,607deaths and 207missing persons) and is still increasing in Fukushima Prefecture. The number of disaster-related deaths is the number of those who died due to the exacerbation, etc. of injuries sustained due to the Great East Japan Earthquake, and it represents the number of those who received payments of disaster condolence grants, based on the Act on Provision of

Disaster Condolence Grant. Many of them were older than 60 years, and had history of various diseases before the earthquake and tsunami. Causes of deaths were mental and physical fatigue during the movement to the temporary housing or during the stay in temporary housing, lack of availability of medical care of their old and new diseases, and various mental and physical fatigue due to the change of social circumstances after the disaster (60, 61). Although no deaths related to radiation exposure has been reported, many residents died and suffering from the diseases in order to avoid radiation.

ConclusionThe amount of radioiodine released to the environment following the Fukushima accident was approximately one-tenth of that in the Chernobyl accident. Residents near the FDNPS were evacuated within a few days and foodstuffs were controlled within one or two weeks. Therefore, thyroid radiation doses were less than 100 mSv (intervention levels for stable iodine administration) in the majority of children even living in the evacuation areas. However, thyroid screening of all children (0-18 years old) in the Fukushima Prefecture was started from 2011, and to date, screening of more than 280,000 children has resulted in the diagnosis of thyroid cancer in 90 children (approximate incidence, 300/million). Incidence of childhood thyroid cancer has been reported to be 1-2/million before the accident and 40/million at the peak after the Chernobyl accident.

Based on the scientific interpretation of the updated results of examinations on radiation doses and health effects, extensive risk communication or dialogue among all stakeholders; afflicted residents, local and central governments, various experts related nuclear disaster, producers as well as consumers in Fukushima and other areas of Japan is essential for the future of Fukushima (62).

Key points:

- The accident of the TEPCO Fukushima Daiichi Nuclear Power Stations (FDNPS) on 11 March 2011 resulted in release of radioiodine to the environment at 120 Peta Becquerel, which is one-tenth of that in the Chernobyl accident.
- Thyroid screening of all children (0-18 years old) in the Fukushima Prefecture was started following the nuclear accident. According to the results of more than 280,000 children, 90 were diagnosed with thyroid carcinoma (approximate prevalence, 300/million).
- Although the thyroid radiation dose was much lower in the Fukushima nuclear reactor accident, the incidence of thyroid cancer has been higher than that following the Chernobyl accident; this difference may in part be due to the increased use of advanced thyroid ultrasound techniques.

Conflict of Interest:

The authors have no conflicts of interest.

Figure legends:

Figure 1.

Heading: Airborne monitoring and recommended areas of evacuation following the Fukushima nuclear reactor accident.

Legend: (a) The results of airborne monitoring by MEXT and DOE, as expressed in $\mu\text{Sv/h}$ at 1 meter from the ground on 29 April 2011 [4, 5]. (b) The “deliberate evacuation areas” and “restricted area” (evacuation areas on 12 March 2011) established on 22 April 2011 [2, 3].

Source: (a) [4, 5], (b) [2, 3]

Figure 2.

Heading: Thyroid equivalent doses in Fukushima

Legends: Screening survey of radioiodine thyroid exposure for children performed from March 26 to 30, 2011, by the Nuclear Emergency Response Headquarter and NIRS. (a) Number of persons examined in each village or town in a map of SPEEDI [10, 17], (b) Distribution of thyroid equivalent doses estimated by the results of the screening survey and the intake scenario from 12 March 2011 to the day before measurements [18, 19].

Source: [17], [19]

Fig 3.

Heading: Results of Fukushima Health Survey

Legends: (a) Results of the first cycle thyroid screening in Fukushima Health Survey during 2011-2014 [28]. (b) Number of thyroid cancer cases in Fukushima and age at the diagnosis [28].

Source: [28]

Fig 4.

Heading: Comparison of Chernobyl and Fukushima

Legends: (a) Thyroid radiation doses in Fukushima, Ukraine, and Belarus as dose-response relationships between I-131 exposure and thyroid cancer [10, 37, 38]. (b) Number of thyroid cancer cases in Chernobyl [39] and Fukushima in relation to individuals' ages at the time of the nuclear accidents.

Source: [10], [28, 39]

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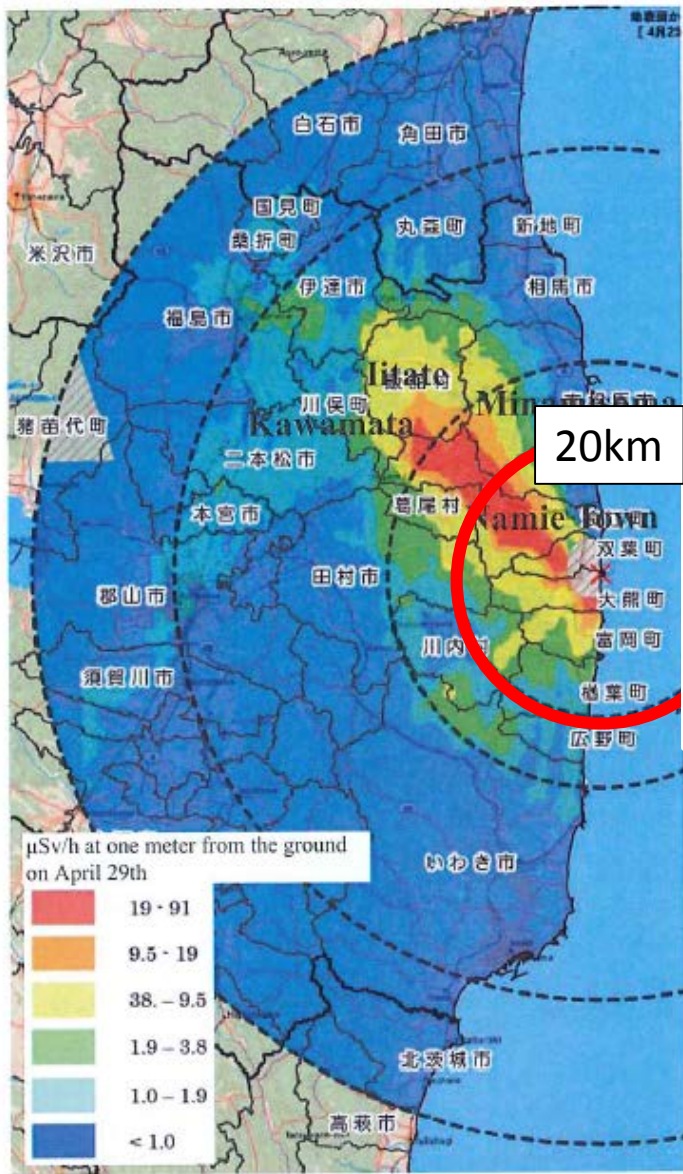
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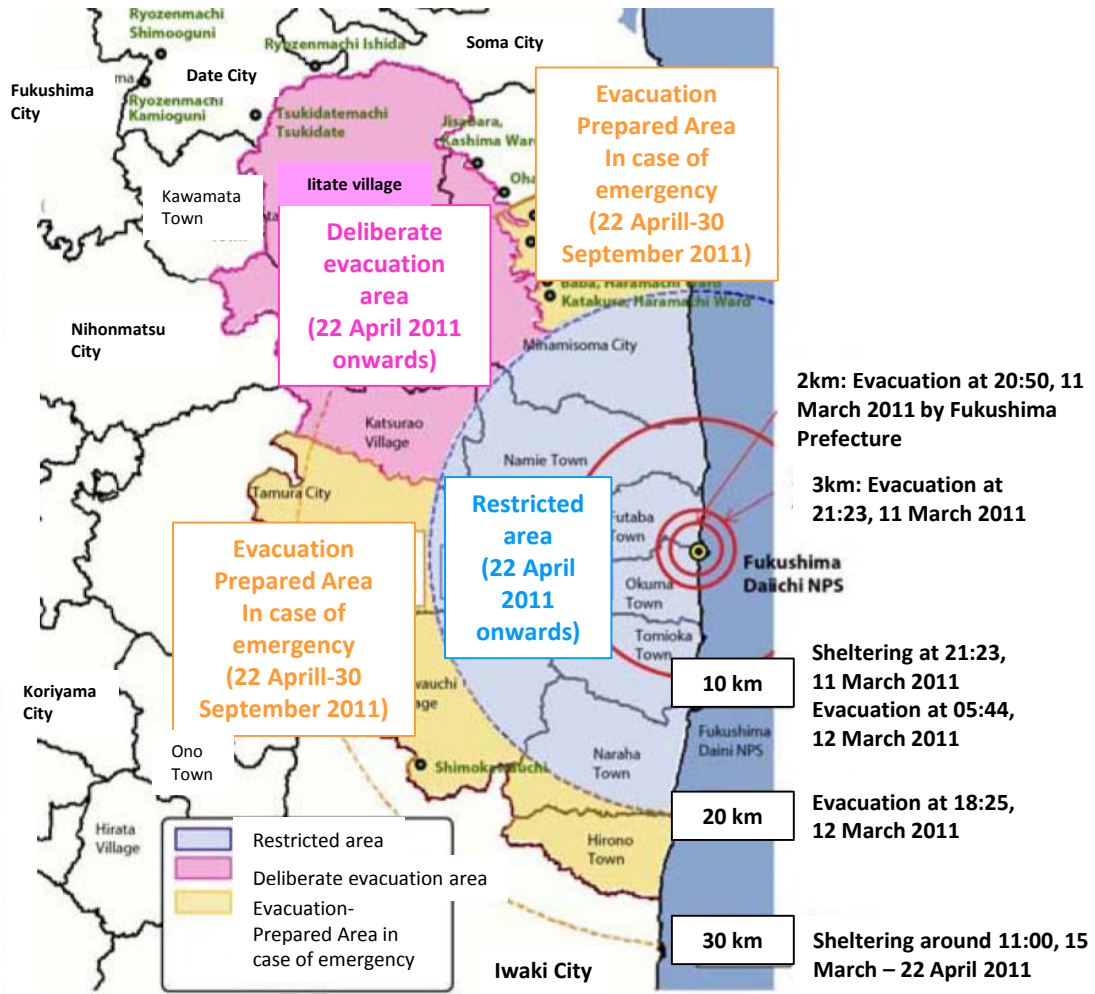
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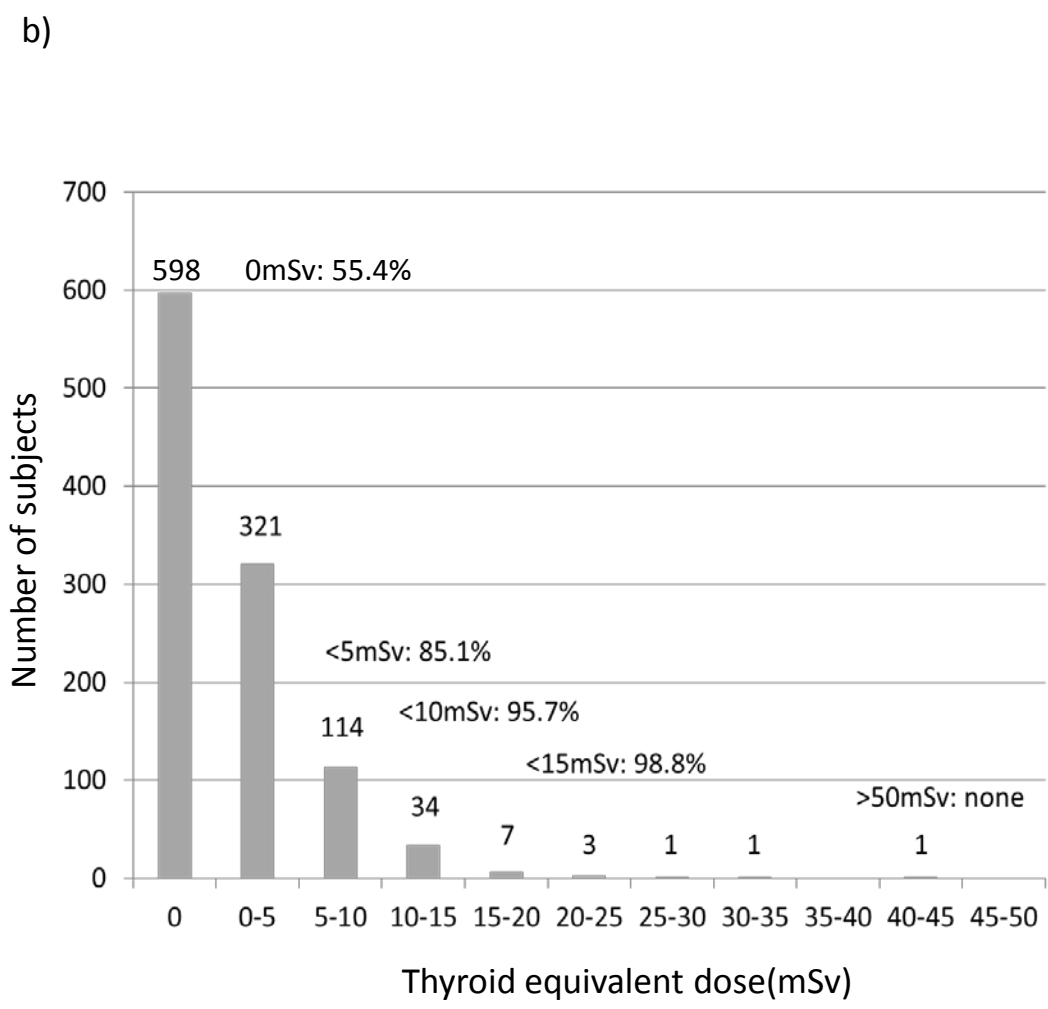
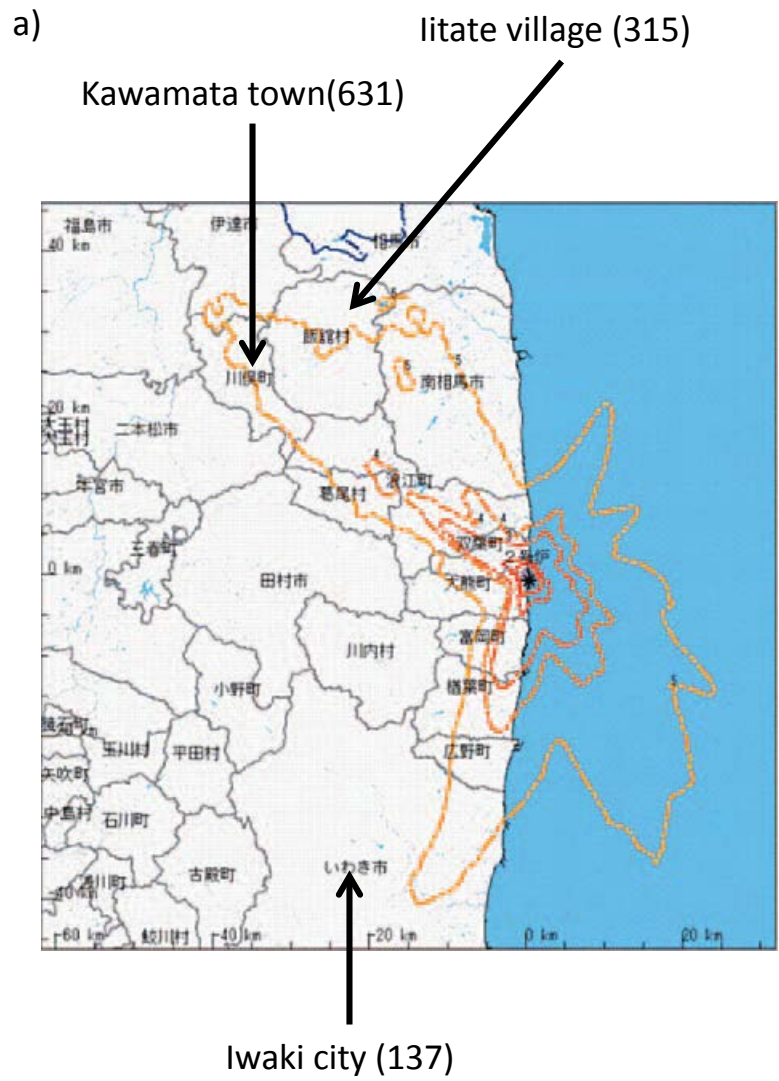
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a)



b)





a)

Total case with malignancy or malignancy suspected	90 (cases)
Sex (male/female)	32/58
Age at diagnosis	16.9 ± 2.7 (8-21 yrs)
Age at the accident	14.7 ± 2.7 (6-18 yrs)
Total operated cases	51 (cases)
Cytodiagnosis	
Benign nodule	1
Papillary carcinoma	49
Others	1
Mean size of tumor	14.2 (mm)

b)

