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Fukushima: Thyroid cancers that should not have occurred

Review of the scientific literature

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Introduction

One of the most important lessons learned from Chernobyl is that the initial exposure to radioactive iodine released from nuclear accidents increases the risk of radiation-associated childhood thyroid cancers. This is explained by the fact that iodine-131 tends to accumulate in the thyroid gland for a few weeks after the release and delivers a dose primarily to that organ. For a given intake, the dose to the thyroid for infants is eight or nine as large as that for adults.

25 years later, during the Fukushima disaster that started on the 11th of March 2011, many people were exposed to the radioactive fallouts. The central government's order to administer prophylactic stable iodine never reached local communities and only few municipalities handed out potassium iodine (KI) pills to their residents based on their own decisions. Iodine was also not distributed in the shelters [GP2012].

Moreover, massive amounts of radiation were being released over 10 days from the Fukushima dai-ichi nuclear power plant and the evacuation of the local population took several days to several weeks in some places like Iitate. Exposure to the radioactive fallouts triggered a lot of anxiety in the Japanese population. This is particularly the case for parents, since children are more sensitive to radiations. A primary health concern among residents and evacuees in affected areas is the internal exposure of the thyroid to radioiodine.

A few months after the accident, the Fukushima prefectural government launched the Fukushima Health Management Survey (FHMS) to evaluate the initial external dose of radiation exposure and to monitor the health conditions of local residents who were likely to have been heavily influenced by the accident. One of the detailed surveys conducted in Fukushima includes thyroid ultrasound examinations.

The primary purpose of the Fukushima Health Management Survey is to monitor the long-term health of residents, promote their future well-being, and determine whether long-term low-dose radiation exposure has health effects [Yasumura 2012].

In this report we shall focus on the results of the thyroid screening that are highly controversial.

Dose evaluation

During the Fukushima disaster, an estimated amount ranging from 2.0×10^{17} to 5×10^{17} Bq (200 to 500 PBq) of radioactive iodine was released into the atmosphere [TEPCO2012, Kobayashi 2013]. About 80% went towards the Pacific Ocean and the other 20% deposited on Japanese territory. The fallout map of radioactive iodine does not coincide with the fallout map of radioactive caesium [Torii 2013, Saito 2015].

In 2013, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimated the average absorbed dose to the thyroid of the Japanese population. Information on dose distribution and uncertainties was not sufficient for UNSCEAR to draw firm conclusions as to whether any potential increased incidence of thyroid cancer would be discernible among those exposed to higher thyroid doses during infancy and childhood [UNSCEAR2014].

According to the UNSCEAR estimation, the average absorbed dose to the thyroid was up to about 35 mGy. For 1-year-old infants, the effective dose was estimated to be about twice that for adults and the dose to the thyroid was estimated to be up to about 80 mGy. UNSCEAR considers that fewer than a thousand children might have received absorbed doses to the thyroid that exceeded 100 mGy and ranged up to about 150 mGy. The risk of thyroid cancer for this group could be expected to be increased. However, it would be difficult, if not impossible, to identify precisely those individuals with the highest exposure. The UNSCEAR also considers that these dose estimates may overestimate actual exposures [UNSCEAR2014].

The evacuation of the population living within the 20-km zone considerably reduced doses to the evacuees. The UNSCEAR estimated that effective doses thus averted ranged up to 50 mSv for adults; the absorbed doses to the thyroid of 1-year-old infants averted by evacuation ranged up to about 750 mGy [UNSCEAR2014].

The UNSCEAR concludes that most of the absorbed doses to the thyroid were in a range for which an excess incidence of thyroid cancer has not been observed in epidemiological studies. These conclusions are frequently quoted in the scientific literature to support that the increase of radiation-related risk for thyroid cancer is highly unlikely. See e.g. [Yamashita 2016, Yamashita 2018]. However, the UNSCEAR also notes that doses towards the upper bounds of the ranges could imply an increased risk for individuals that among sufficiently large population groups might lead to discernible increases in the incidence of thyroid cancer due to the radiation exposure, in particular for infants and children. The number of infants that may have received thyroid doses of 100 mGy is not known with confidence; cases exceeding the norm are estimated by model calculations only, and in practice they are difficult to verify by measurement [UNSCEAR2014].

Finally, the UNSCEAR considers that the occurrence of a large number of radiation-induced thyroid cancers as were observed after the Chernobyl accident can be discounted because doses were substantially lower [UNSCEAR2014].

It is worth noticing that the World Health Organisation (WHO) assessment lead to higher estimated doses to the thyroid although there are also locations where the estimated doses by the UNSCEAR were higher than those in the WHO study [WHO2013]. A recent study also reassessed the early ^{131}I inhalation doses to the thyroid and with values almost congruent with the outcomes of previous investigations except for the contribution of highly contaminated plumes on the 12th and 15th of March 2011 that carried the potential to significantly increase the thyroid doses to residents [Takagi 2020].

Lessons from Chernobyl

Since the end of the last century, there has been little dispute that the Chernobyl accident resulted in a significant increase in thyroid cancer among young people in Belarus, Ukraine and, to a lesser extent, the Russian Federation. However, the first evidence identified about four years after the accident [Kazakov 1992, Baverstock 1992] were broadly met with a mixture of surprise and scepticism because the unexpectedly large increase in the number of thyroid cancer cases in children started considerably earlier than expected. Sceptics were suggesting reporting and screening effects to dismiss the link with the nuclear accident [Shigematsu 1992, Ron 1992]. In 1991, the Institute for protection and nuclear safety (IPSN), the French Technical Support Organisation, wrote[1] that *"the health authorities of the Republics of Ukraine and Belarus have reported cases of thyroid pathologies in excess of the normally observed frequencies. Foreign observers who have had results and have carried out speciality examinations are more reserved"* [IPSN1991].

Several arguments have led to the current consensus [Abelin 1994]: cancer registries in other countries reported considerably lower incidences for childhood thyroid cancer than that in Belarus, indicating that only a small part of the increase could be due to improved reporting of cases since the accident at Chernobyl. Moreover, the regional distribution of contamination with iodine-131 roughly corresponds to the areas of high incidence in southern Belarus. The age distribution of the patients also suggests an association with the accident. In the decade preceding the accident only one of the 10 children was aged under 10 at diagnosis, but the proportion of children under 10 increased to over 50% among the cases reported in 1990 and 1991. None of the children in the cases reported in 1990 and 1991 was born after 1986. This is compatible with a higher susceptibility to radiation among younger children.

About 20 000 thyroid cancer cases were registered from 1991 to 2015 among people who were under 18 in 1986 and lived in the affected areas of the former Soviet Union, according to the latest study by the UNSCEAR, which was released in 2018. This number is almost three times higher than the number of thyroid cancer cases registered in the same cohort in the period 1991−2005. The Committee estimated that the fraction of the incidence of thyroid cancer attributable to radiation exposure among non-evacuated residents of Belarus, Ukraine and the four most contaminated oblasts of the Russian Federation, who were children or adolescents at the time of the accident, is of the order of 0.25. The uncertainty range of the estimated attributable fraction extends at least from 0.07 to 0.5 [UNSCEAR2018].

[1] *« Les autorités sanitaires des Républiques d'Ukraine et de Biélorussie ont rapporté des cas de pathologies thyroïdiennes en excès par rapport aux fréquences observées normalement. Les observateurs étrangers qui ont eu communication des résultats et qui ont procédé à des examens de spécialités sont plus réservés. »*

The Fukushima Health Management Survey

Survey description

A health survey of the local population (the Fukushima Health Management Survey, FHMS) was announced in July 2011[2] and launched in October 2011. It includes a thyroid ultrasound examination (TUE) of 360 000 children aged up to 18 years at the time of the accident (born between 2 April 1992 and 1 April 2012). Individuals from Fukushima Prefecture, including evacuees living in other prefectures, are proposed to undergo thyroid examinations every 2 years until age 20 and every 5 years thereafter. Non-Fukushima residents who stayed in the prefecture from 11 March 2011 to 26 March 2011 are also eligible for the program.

The Fukushima Health Management Survey is funded by the central government and commissioned by the prefectural government to the prefectural-run Fukushima Medical University (FMU) which is presently terminating the fourth screening campaign and started the fifth one in April 2020.

Children and adolescents with cysts with a diameter larger than 20 mm or with nodules larger than 5 mm are selected for secondary examination which may consist in a cytological analysis of thyroid tissue taken from biopsies by fine-needle aspiration. If cancer is diagnosed, children may have part or all of their thyroid gland removed. But this is not systemically the case. The confirmed results of suspicious malignancy and malignant cases are discussed in detail with the patients and their guardians, who would then elect either surveillance or surgery [Sakamoto 2020].

Some thyroid cancers will progress to clinically apparent thyroid cancer and should be surgically treated, while others might never progress in the patient's lifetime. However, ultrasound examinations and aspiration biopsy cytology cannot differentiate between these types. The various guidelines available for the treatment of thyroid cancer are also based on experiences with adults, not children, and the natural course of thyroid cancer in children is not known. Differentiation between radiation-induced cancer and sporadic thyroid cancer is also not possible by clinical examination alone [Nagataki 2016].

Results of the survey are regularly published on the website of Fukushima Prefecture. The most recent data were published on the 15th of January 2021 and report the situation as at 30 June 2020 [PHS2021].

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[2] The Mainichi, *Fukushima to provide lifetime thyroid tests in wake of nuclear crisis*, 25 July 2011; The Asahi Shimbun, *Fukushima to provide life-time cancer checks*, 25 July 2011.

For the first three screening campaigns, as well as for young residents over 25 years old, the detailed data were published in earlier reports.

Most recent data

The total number of thyroid cancer or suspected cancer cases discovered so far within the survey programme is 252. Among them, 203 underwent surgery. One nodule turned out to be benign (first campaign). For the 202 other cases, the cancer was confirmed (papillary carcinoma: 199, poorly differentiated carcinoma: 1, follicular carcinoma: 1, other thyroid carcinoma: 1).

Results of the official monitoring are summarised in Table 1.

Table 1: Official results of the thyroid examination within the Fukushima Health Management Survey

	Number of eligible people	Number of results (%)	Number of secondary examinations with results	Number of cytological diagnosis	Number of suspected thyroid cancers	Number of cancers confirmed after surgery
First campaign (at 31/03/18)	367 637	300 472 (81.7%)	2 091	547	116	101
Second campaign (at 31/03/18)	381 244	270 529 (71.0%)	1 826	207	71	54
Third campaign (at 31/03/20)	336 670	217 920 (64.7%)	1 060	78	31	27
Fourth campaign (at 30/06/20)	294 240	180 978 (61.5%)	758	64	27	16
Fifth campaign (at 30/06/20)	252 821	41	0	0	0	0
Over 25 years old (at 31/03/20)	66 637	5 234	160	13	7	4

It is worth noticing that these numbers only include cancer cases discovered within the Thyroid Ultrasound Examination (TUE) programme as a part of the Fukushima Health Management Survey. In [Yokoya 2019], 11 additional thyroid cancer cases that were not included in the TUE programme by the 30th of June 2017 are mentioned. They were not officially added to the results of the thyroid screening, although they were treated at the Fukushima Medical University Hospital. The number of additional unofficial cases since June 2017 is not known.

Data in Table 1 shows that nearly 80% of the suspected cases underwent surgery. Out of 125 cases of the first two campaigns, total thyroidectomy was performed in 11 (8.8%) cases, and lobectomy or hemithyroidectomy in 114 (91.2%) cases [Yamashita 2018]. These figures were not updated in more recent publications from members of the health survey who keep reporting old data [Sakamoto 2020].

In June 2019, the *3.11 Fund for Children with Thyroid Cancer*[3] revealed that 14 people in Fukushima prefecture had a second surgery. For 12 of them, this was due to the recurrence of metastasis[4]. There is no mention of these cases with second surgery in the recent publication from members of the health survey [Sakamoto 2020].

Preliminary Baseline Screening and Full-Scale Screening

Given that the number of children who developed thyroid gland cancer started increasing four or five years after the 1986 Chernobyl nuclear disaster, the Fukushima prefectural government initially planned to begin the health checks on children in 2014. But after parents demanded an earlier implementation of the tests, the prefectural government moved up the schedule.

When the health survey was launched in October 2011, Shinichi Suzuki, professor of surgical medicine at Fukushima Medical University declared to the Asahi Shimbun[5]: *"It is highly unlikely that any symptom on thyroid glands caused by radiation will be detected (only seven months after the nuclear accident started), but we want parents to know the current condition of their children's thyroid glands, which we hope will reassure the parents that their children are OK now."* And, Fukushima Medical University Vice President Shunichi Yamashita[6], who also serves as the president of the Japan Thyroid Association, added: *"It is highly unlikely that we will detect any thyroid abnormalities at this stage. However, we hope that this program will relieve many residents."*[7] We can also find similar confidence in the early scientific literature presenting the survey [Yasumura 2012]: *"Because the increase in thyroid cancer was reported to start 4 or 5 years after the Chernobyl accident, we expect no excess occurrence in the first 3 years in Japan."* Note that at the time of the article (March 2012), no malignancy was detected. The first cancer case was reported on 11 September 2012, exactly a year and a half after the accident.

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[3] https://www.311kikin.org/

[4] ourplanet-tv.org, 甲状腺がん子ども基金１４９人に給付～福島での再発転移１２人, 17 June 2019

[5] The Asahi Shimbun, *Thyroid gland radiation checks start amid parents' anger*, 11 October 2011

[6] Shunichi Yamashita also contests the use of the linear no-threshold (LNT) cancer risk model and worries more of prolonged "radiation phobia" [Yamashita 2014].

[7] The Mainichi Shimbun, *Fukushima starts thyroid check-ups for children, but many problems are still unsolved*, 12 October 2011

Two years later, these scientists wrote in a scientific article that *"the prevalence of disease is expected to rise due to the implementation of routine thyroid ultrasound screening in Fukushima"* [Yamashita 2013]. As shown in Table 1, the number of thyroid cancer cases discovered during the first screening campaign is some tens of times greater than the usual observed occurrence among young people in Japan. This high detection rate of thyroid tumours caused a great deal of concern among children and parents. The organisers of the survey changed their stance.

Since the expected latency for radiation-induced thyroid cancer in children is considered to be 4 to 5 years based on the Chernobyl data, these early cases in Japan were considered as latent cancers discovered by the intensive screening. The fact that the examination period was within 3 years after the nuclear accident is used as an argument to claim that these cancer cases are not radiation induced. See e.g. [Shimura 2018].

Since there were no epidemiological data on childhood thyroid cancer rates in Japan prior to the Fukushima accident, similar surveys were conducted from November 2012 to January 2013 on 4 365 children and adolescents (aged between 3 and 18 years) in the prefectures of Aomori, Nagasaki and Yamanashi [Taniguchi 2013, Hayashida 2013]. Although these studies include a small number of subjects, it showed similar prevalence rates of thyroid cysts and nodules. Note that the age range and sex distribution does not fit with the Fukushima survey. A single cancer case was detected (papillary carcinoma in a female who was more than 15 years old) and reported later [Hayashida 2015]. The incidence of thyroid cancer among tested children of these three prefectures is lower than that of the first survey in Fukushima, but with a single case, it is difficult to draw definitive conclusions on this point. The small size of the study cohort leads to a high margin of uncertainty.

Finally, the first-round screening in Fukushima which was called "Initial Survey" at first, was later renamed "Preliminary Baseline Survey." The subsequent rounds are called "Full-Scale Survey". The goal is to compare the full-scale survey data with data from the preliminary baseline survey in order to determine any increase in thyroid cancer over time, as explained in [Suzuki 2016].

The results reported in Table 1 show that total number of cancer cases detected in the Full-Scale Survey (136) surpasses the number of cases detected during the first campaign considered as baseline (116). The difference is not statistically significative, but with the ongoing screening, the number of cases detected in the successive campaigns will keep increasing, as it is observed in the territories affected by the Chernobyl disaster.

Screening effect and over-diagnostic?

Organisers justify the survey by the questions raised regarding the health effects of radiation exposure, which led to increased anxiety among the Fukushima residents about the possible development of thyroid cancer. However, the only explanation brought so far for the high occurrence rate in Fukushima prefecture is the screening effect, even if the supposed latency is over. Impact of the radioactivity is excluded.

Two articles try to estimate the screening factor. In [Jacob 2014], the model leads to the expectation that the ultrasonography survey of residents of Fukushima Prefecture will increase thyroid cancer incidence compared with thyroid cancer incidence in 2007 in Japan drastically. However, the estimated increase due to screening has a large uncertainty with a best estimate of a factor of about 7 (95 % confidence interval (CI): 0.95; 17.3). The model is based on the results of the surveillance of the thyroid for Belarusian and Ukrainian population groups and estimates the baseline thyroid cancer incidence rate in the Fukushima Prefecture under the conditions of ongoing surveys, assuming no relation to the radiation exposure due to the accident at the Fukushima dai-ichi nuclear plant.

In the other study [Katanoda 2016], the observed/expected ratio of thyroid cancer prevalence for the residents aged under 20 years is calculated. Assuming that during the first three years after the nuclear disaster there is no radiation induced thyroid cancer, the estimated screening factor is about 31 [95% CI: 26.2, 35.9]. Thus, the observed/expected ratio of thyroid cancer prevalence is significantly larger than the modelled ratio of the other study, assuming a screening effect.

Of course, latent thyroid cancers are discovered earlier with the screening. And these two studies may indicate that all observed cases are not explained by the screening. Considering the difficulties to estimate the impact of screening on the observed cases, it is not possible to ascertain that the remarkably high prevalence of thyroid cancer observed in Fukushima is entirely due to screening. Such a claim is a personal opinion, not a scientific fact.

If thyroid cancers are found before any symptoms emerge because of the screening, why have many persons already undergone surgery without waiting for clinical signs? Some scientists suggest over-diagnostic as an explanation. By "over-diagnosis" they mean that they examine cases that would not otherwise cause symptoms or death during a patient's ordinarily expected lifetime. Unnecessary surgeries would eventually give children not only scars on their necks, but also the stigma that they had developed cancer due to radiation exposure. It would probably affect their eligibility for cancer insurance, and they might face discrimination in marriage or other contexts for having been exposed to radiation. However, the over-diagnostic is contested by the Fukushima Medical University that conducts the surgery, because it questions the quality and the reliability of the thyroid cancer diagnostics. Shinichi Suzuki, professor of thyroid surgery at Fukushima Medical University, who has operated on most thyroid cancer patients at the university, presented evidence at the Japanese Society of Thyroid Surgery that among 145 patients who were operated on, about 78% had lymph node metastasis, and about 45% showed invasive growth. Based on these facts, he said that over-diagnosis is unlikely [Sakiyama 2020].

In 2015, the same S. Suzuki concluded that *"the thyroid cancers identified in this survey so far are unlikely to be due to radiation exposure, and are more likely to be the result of screening using highly sophisticated ultrasound techniques"* [Suzuki 2016]. One of his arguments is that there were no cases in children aged 0-5 years old.

Cancer cases among 0-5 years old children at the time of the accident

The assumed five years latency of the thyroid cancer that is the cornerstone of the official interpretation of the survey data leads to pay a special attention to children who were less than 6 years old at the time of the nuclear disaster. Assuming this latency, we can exclude from these children, first preclinical manifestations of abnormality before the nuclear accident.

In Belarus starting from 1990, the incidence of thyroid cancer increased greatly in children who were aged 0–5 years at the time of the accident, which suggests that this age group is particularly vulnerable to the effects of radiation [Takamura 2016]. In the early years of the survey in Fukushima prefecture, the absence of cases found in the most vulnerable group of very young children was emphasised to suggest that the increase is due to the screening rather than radiation exposure, even if it was too early to draw such a conclusion [Takamura 2016, Saenko 2017].

In March 2017, the *3.11 Fund for Children with Thyroid Cancer* announced that a child who had a thyroid cancer was missing in the official records: he was 4 when the nuclear accident occurred and had surgery at Fukushima Medical University in 2016[8]. The support group said it asked the prefecture-run Fukushima Medical University, that is in charge of the survey, whether any patient who was 4 or younger at the time developed thyroid cancer, and was assured that none did[9]. The university explained that cases followed-up under regular medical insurance are deemed outside the boundaries and responsibilities of the survey, with no obligation or actual system to collect such data for reporting. The case of the 4-year-old remains excluded from the official count [Hiranuma 2017].

Nowadays, there are officially 8 cases of thyroid cancer in children who were less than 6 years old at the time of the nuclear accident. See Figures 1, 2 and 3. During the fourth campaign, the latest data disclosed in January 2021 show the case of a child who was less than one, and another one who was 2 (Fig. 3). For these children, we can exclude first preclinical manifestations before the nuclear accident.

If these cases are not a proof that these cancers are due to radiations, such a possibility cannot be excluded anymore.

[8] The Associated Press, *Fukushima child's case not found in Japan thyroid cancer records*, 31 March 2017.
[9] Kyodo News, *Boy's thyroid cancer casts doubt on Fukushima's denials*, 31 March 2017

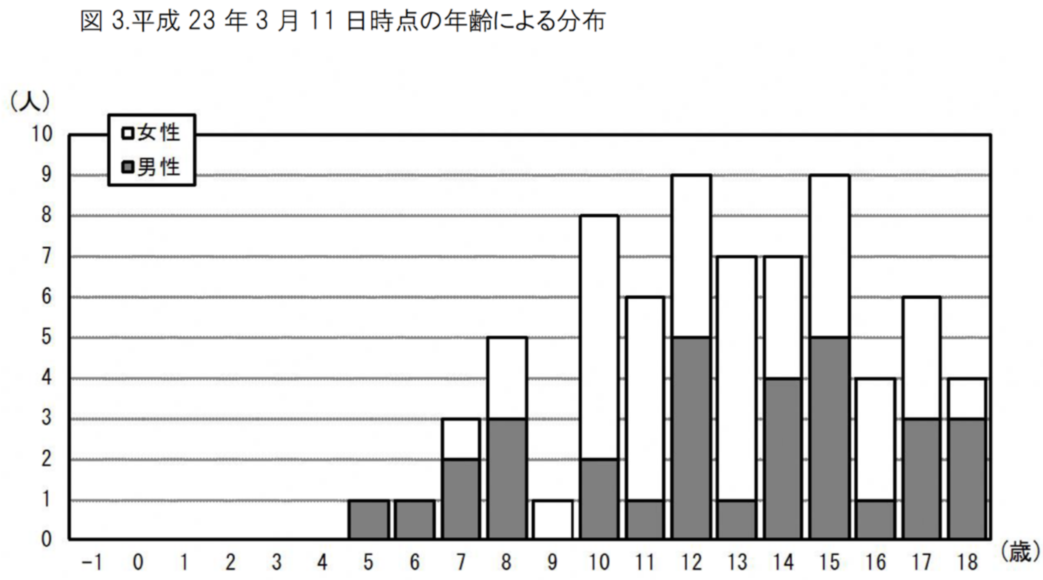

Figure 1: Distribution by age at 11 March 2011 for the 71 cases discovered during the second campaign. White is for girls and grey for boys. Figure reproduced from [PHS2018].

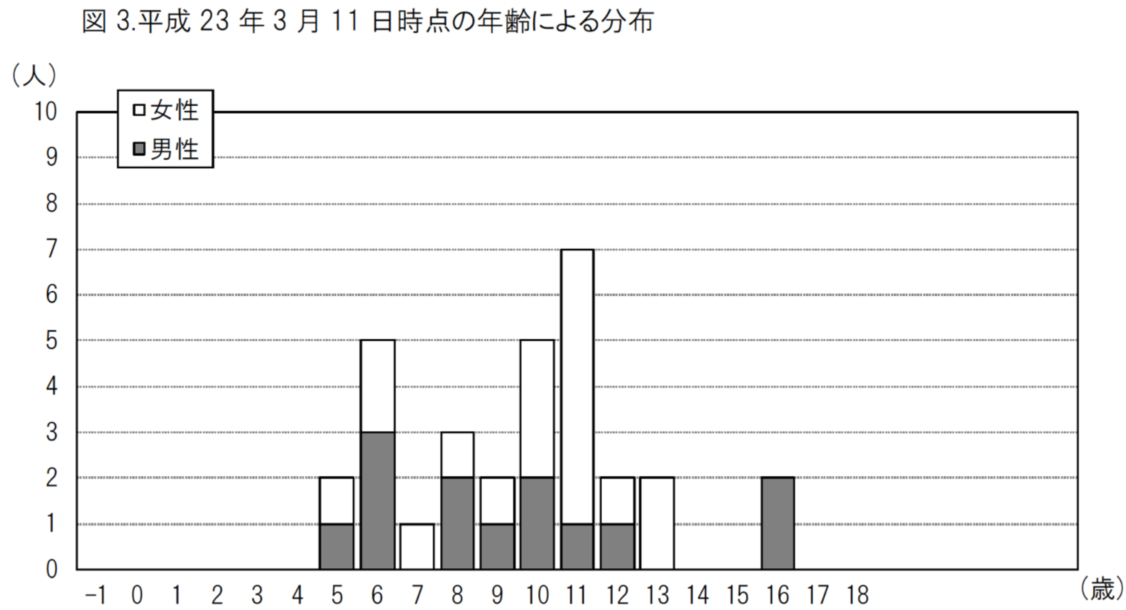

Figure 2: Distribution by age at 11 March 2011 for the 31 cases discovered during the third campaign. White is for girls and grey for boys. Figure reproduced from [PHS2020].

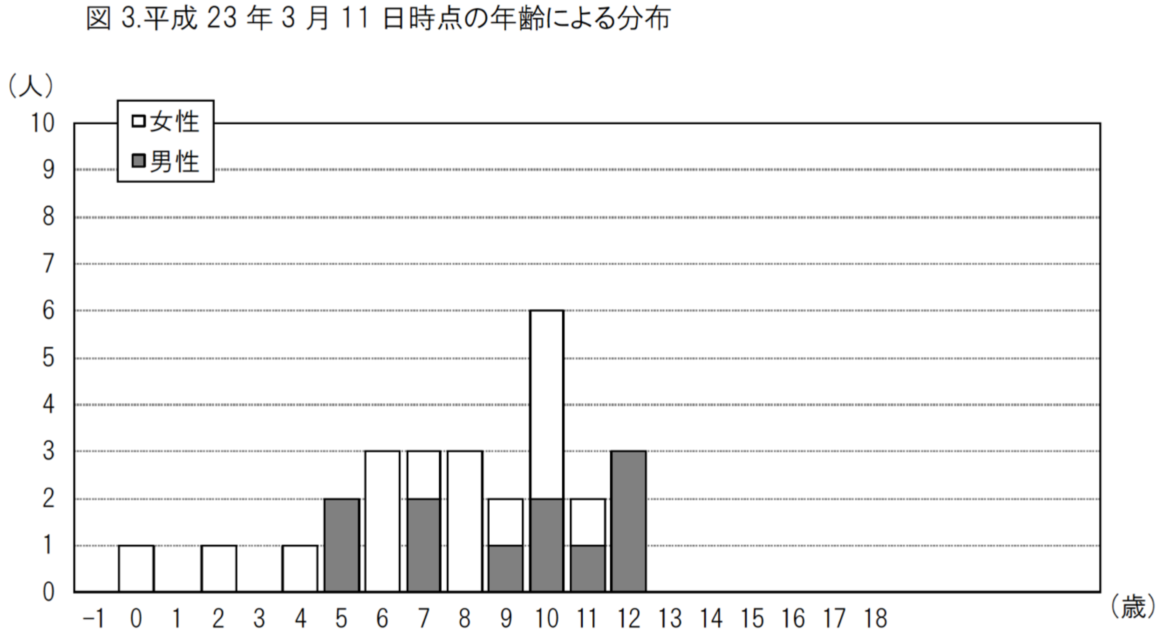

Figure 3: Distribution by age at 11 March 2011 for the 27 cases discovered during the fourth campaign. White is for girls and grey for boys. Figure reproduced from [PHS2021].

Latency

In Chernobyl, small excesses of thyroid cancer incidence were observed in both Belarus and Ukraine during 1987–1989, within 3 years after the accident in 1986. However, no screening was conducted during these three years. Clinical signs lead to the discovery of early thyroid cancers [UNSCEAR2018].

In Fukushima prefecture, for 71 suspected cancer cases found during the second-round screening, their first-round results were no nodules or cysts found (grade A1) for 33 of them, and nodules with a diameter lower than 5.0 mm or cysts lower than 20.0 mm (grade A2) for 32 of them. Only 5 of them had nodules or cysts larger than this limit (grade B). One case did not undergo the first round [PHS2018]. This means either misdiagnoses during the first-round or rapid growth of cancerous lesions in 2-3 years, contradicting the assumed latency for childhood thyroid cancer. Misdiagnose is rejected by the organisers of the survey, but no clear explanation is provided for such a short time lapse.

Results are similar for the 31 cases of suspected thyroid cancers discovered during the third-round: 21 were graded A (7 A1 and 14 A2), 7 were graded B, and 3 were not examined during the second-round. And for the 27 suspected cases discovered during the fourth-round, 21 were graded A (5 A1, 16 A2), 5 B and 1 had not been examined during the previous round.

Note that the World Trade Center Health Program of the US Centers for Disease Control and Prevention considers a latency of one year for childhood cancers and 2.5 years for thyroid cancers in adults to be eligible for coverage in the WTC Health Program [WTCHP2014].

Link to the radioactive fallout

Since it is not possible to distinguish between prevalent and incident cancer cases, several studies have looked for a statistical link between the incidence of thyroid cancers and exposure to radioactivity. The results are contradictory and have triggered hot debates in the scientific literature. The main reason comes from the fact that complete datasets of individual doses are unavailable. Surrogate methods or models are necessary to evaluate the individual doses.

Due to the evacuation orders, many people were displaced during the early days of the nuclear disaster. Some went to less contaminated places while others were sent downwind of the radioactive fallouts where they were exposed to a higher dose than that without evacuation. In places were the evacuation order was issued in April 2011, more than a month after the massive radioactive releases, some of the inhabitants had already escaped on their own while others were still there [GP2012]. Thus, it is very difficult to trace back the children's itinerary and evaluate the exposure dose.

Moreover, the number thyroid cancer cases is only known for the 59 municipalities of origin in Fukushima prefecture, within which the radioactive ground contamination may vary greatly. And there are many municipalities where the number of cancer cases is zero or small due to the fact that the number of children in the community is small. Neighbouring municipalities with similar radiation levels are generally grouped in order to get areas with a meaningful number of thyroid cancer cases, but it is not the case in all studies.

The screening in the first round of examinations in Fukushima began earlier in areas with the highest contamination levels, thus the time between the accident and the screening was shorter, leaving less time to hypothetical induced cancers to develop. This schedule may have introduced a bias in the analysis that is acknowledged in several studies mentioned below.

In the first study of this kind [Tsuda 2016], Fukushima prefecture was divided into 9 districts depending on the radioactive surface contamination of the soil, used as a surrogate for exposure estimation. The less contaminated district was then used as a baseline to study the spatial distribution of the thyroid cancer cases in the other districts. Since it was an early study, it mainly considered the cancer cases discovered during the first screening. Assuming a 4-year latency for all cases, its main conclusion is that the result was unlikely to be fully explained by the screening effect. However, the highest prevalence odds ratio obtained in this study is not in the most contaminated district. And the 95% confidence intervals of the odds ratios of all districts include 1, which means that we cannot exclude a uniform spatial probability to develop a thyroid cancer. Thus, it is difficult to draw definitive conclusions at this stage. Note that this study triggered many critical comments in the scientific literature.

Another study of the spatial distribution of the thyroid cancer cases discovered during the first round by members of the Fukushima Health Management Survey Group [Nakaya 2018] found no significant spatial anomalies/clusters or geographic trends of thyroid cancer prevalence among the ultrasound examinees, indicating that the thyroid cancer cases detected are unlikely to be attributable to regional factors, including radiation exposure.

More recently, other scientists studied the results of the first and second examination campaigns in the relation with radiation exposure. In [Yamamoto 2019, Yamamoto 2021], the average external effective dose-rate per municipality of the Fukushima prefecture was used as a proportional surrogate exposure measure for the internal dose of the thyroid gland. In both the first and second rounds of investigation and in both cycles combined, this study found a clear positive and significant dose response relationships between the thyroid cancer detection rate and the external effective dose-rate.

A group of physicists [Toki 2020] used detailed deposition maps of gamma-ray emitting radioactive nuclides in eastern Japan based on extensive soil sampling in addition to air dose measurements conducted shortly after the Fukushima accident [Saito 2015] to study the results of the first and second examination campaigns. The whole prefecture was divided into six areas. For the cancer cases discovered during the first round of the survey, no correlation was found with the radioactive contamination. The cancer cases discovered during the second round of examination show a positive correlation with the ambient dose rate. However, with the radioactive iodine, the dependence of the number of cancers to the dose is weak and cannot be demonstrated.

The cancers discovered during the second round of examination were also analysed in [Ohira 2020], by members of the Fukushima Health Management Survey Group who found no correlation with the average estimated doses per municipality evaluated by the UNSCEAR. Both internal and external doses were taken into account. This study is disputed in [Yamamoto 2021].

Conclusions

As mentioned in the introduction, one of the primary goals of the thyroid examination survey is to determine whether low-dose radiation exposure has health effects. However, the former Director of the Radiation Medical Center for the Fukushima Health Management Survey, Shunichi Yamashita, already concluded that *"although health effects directly related to radiation exposure are highly unlikely under the current circumstances and radiation levels in Fukushima, an increase in childhood thyroid cancer in Chernobyl due to internal exposure to radioactive iodine exaggerated the uncertainty of low dose radiation health risk and also stirred up a fear of radiation"* [Yamashita 2016]. Whatever the results, such an interpretation is kept along this line by the organisers of the survey.

In [Suzuki 2016], it is also stated that the cases of thyroid cancer discovered during the first campaign were not a result of radiation exposure after the Fukushima dai-ichi accident. Such a conclusion is based on several reasons. First, most of the target population received low doses. However, the UNSCEAR does not exclude few cancer cases related to radiations. Second, the expected latency for radiation-induced thyroid cancer is 4 to 5 years. Most of the cancers discovered from the second campaign appeared in a very short time. Third, no occurrence of cancer was found among the youngest age group, 0 to 5 years, during the first campaign. We saw that there are more than 8 such cases in the following campaigns.

Regarding the statistical correlations with the exposure doses, the available data are not detailed enough to allow accurate studies. Interestingly, studies by members of the Fukushima Health Management Survey Group always found no correlation with the radiation doses whereas studies by external researchers find such correlations.

Ten years on from the Fukushima disaster, it is still not possible to draw definitive conclusions on the reasons behind the large increase of the thyroid cancer rate among young people from Fukushima. However, it is not possible to exclude radiation induced cancers.

To improve the statistical studies, all cases of thyroid cancer should be registered. Moreover, the precise anonymized individual data on where the participants lived, when the screenings were carried out, and when the diagnoses were established, should be transferred to external researchers under conditions that protect the patient. This is currently not the case [Yamamoto 2019].

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