Environmental radiation measurements immediately after the accident and dose evaluations based on soil deposition

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In the Nuclear Safety Technology Center, we have measured the environmental radiation on a voluntary basis after the accident along with supporting activities based on the request of the government. In this paper, we report the results of the major voluntary measurements (immediately after the accident, after a few weeks, and after a few months). In particular, the radioactive plume that passed through on the morning of 15th March, 2011 at Bunkyo-ku Tokyo, is reported to have peaked at 10:05 am. Additionally, as the exposure has been evaluated from soil deposition based on these measurements, inhalation exposure of radioactive cesium has been rated as reducing to less than one tenth in the next 10 years.

Key Words: *radioactive plume, dose evaluation, MCNP5, RESRAD6.5*

1. Introduction

The Nuclear Safety Technology Center (NUSTEC) is a public foundation, responsible for conducting radiation and nuclear safety activities such as the operation of SPEEDI. During the first three months after the Fukushima Daiichi nuclear power plant accident (1F), we have provided assistance to the government 24 hours a day with a staff of more than 80 people working on a rotating shift. This assistance included aerial monitoring in cooperation with the U.S. Department of Energy (DOE) and dose calculation for atmospheric dispersion prediction by SPEEDI. In addition, as a voluntary activity, we carried out environmental radiation monitoring activities from the initial stage of the accident. In this paper, we report the results obtained by our monitoring staff during the move from Tokyo to Fukushima Prefecture and Aomori to Fukushima. In addition, we report the results of the evaluation from the deposition of radioactive material and the exposure conditions of the movement of the radioactive plume on 15th March, 2011 which are derived from the results of these measurements. These contents, aspire to become a reference for the next generation of nuclear safety.

2. Voluntary radiation measurement

(1) Immediately after the accident phase

2011.3.12

NUSTEC staff reported their arrival at the off-site center, 5 km southwest of the 1F site but could not confirm the increase in radiation dose.

2011.3.15 2:00-13:00

Intermittently measuring radiation at Bunkyo-ku Tokyo

2011.3.15 8:30-12:00

Replacement is moved towards Fukushima city from Tokyo. The staff confirmed an increase in radiation dose at the Tohoku Expressway.

2011.3.15 11:00

Another member of the NUSTEC staff (Arial Monitoring staff) checked the increase in radiation

dose (1μSv/h) at the Ono-machi General Athletic Park; and they then induced sheltering (in gymnasium) evacuees coming from Hirono. (12:30 10μSv/h)

2011.3.16 10:03-21:00

Replacement is moved towards Fukushima city from Aomori. The staff also confirmed the increase in radiation dose in the northern part of Tohoku Expressway. (Table 1)

(2) After a few weeks phase

2011.3.19

Radiation dose at Fukushima prefectural office building: 4.2μSv/h

2011.3.21 10:50

Radiation dose in SA of Tohoku Expressway in Tochigi 1.2μSv/h

During this time, the voluntary measure has not been carried out in support of the aerial monitoring with DOE.

2011.4.2 to 2011.4.3

Radiation dose in Fukushima and Tochigi area (Fig.2)

2011.4.7 13:00–13:50

Radiation dose in the Sukagawa city route 118 (0.35–1.37μSv/h)

2011.4.8 Fukushima area (Table 2)

(3) After a few months phase

2011.4.17 14:53–16:57

Radiation dose in Tokyo area (Table.3)

2011.5.14 to 2011.5.15

Radiation dose in Johban-Banetsu expressway (Table 4)

2011.5.23

Radiation dose in the western part of Fukushima.(4.(1))

3. Radioactive plume passing through Tokyo area

(1)Early morning of 15th March, 2011

According to the measurement done by Japan Chemical Analysis Center, around 4:00 am on 15th March, a slight increase in the amount of radiation has been observed.[1] In Hakusan, Bunkyo-ku, Tokyo, significant increase in the dose was not observed, as shown in Fig.1. However, an increase in dose has been confirmed by the monitoring post at Kawasaki, Yokosuka from 4 am to 5[2]. In addition, at 11 am, rising dose has been observed at the monitoring post in Shizuoka Prefecture[3]. In addition, in the monitoring post near Hokota Ibaraki located northeast of Tokyo, an increase in radiation dose has been observed at about 2 am.[4]

Therefore, the cause of this increase in radiation dose can be attributed to the radioactive plume. This radioactive plume reached the Shizuoka Prefecture from Tokyo Bay by way of Kanagawa Prefecture. The emission source can be determined from the relationship between distance and velocity; it was previously released from the ventilation at 0:03 am on 15th March.

(2) Morning of 15th, March 2011

Rise in the radiation dose from the radioactive plume has been confirmed between 9:40 am and 10:30 am on 15th March at Hakusan, Bunkyo-ku, Tokyo, as shown in Fig.1. The peak time was 10:05 am. This radioactive plume is estimated by dry ventilation from 1F unit2 at 0:03 am on 15th March. Many researchers have reported that this radioactive plume is moving northward towards Saitama, Gunma and Tochigi Prefecture from Tokyo,

4. Exposure evaluation from soil deposition

It is assumed that there is a life of self-sufficiency in the soil deposition, exposure doses was evaluated in the areas where soil deposited low concentrations (as compared to outside area of 1F) using the measurement results of 1cm dose equivalent rate on 2011.5.23..Fig.3 is shown in the flow diagram of this evaluation.

(1)Radiation dose rate due to radionuclide deposited on soil

To evaluate the exposure dose was measured (about 100m × 100m) where the concentration of such the deposition can be averaged ground soil. In this area measurement was performed at 34 points, 1cm dose equivalent rate at surface was 1.026μSv / h average and at 1m height was 0.897μSv/h average. Fig.4 shows the measurement results as contour plots at the height of 1m. The measured area is located in the western part of Fukushima. (about 8 km west from Fukushima Station JR), this measurement was done to 2011.5.23.At this time, the influence of other radionuclides emitting γ-rays, such as radioactive iodine, was almost negligible.

(2)Estimation of soil deposition concentration

The depth of deposition of radioactive Cesium on the ground soil was 1cm based on spectral analysis of germanium semiconductor detector. Using MCNP5[5] (which was developed by Lawrence Livermore Laboratory, United States), the soil deposition concentrations (Bq/g) taking into accounts the background from ^{40}K and natural Uranium are estimated from the measured 1cm dose equivalent rate. The results are shown in Fig.5 From this estimation, the soil deposition concentration in this area was found to be 4.5 Bq / g. The calculation conditions of MCNP5 are shown in Table 5.

(3) Assessment of exposure dose

It is assumed that there is a life of self-sufficiency in this area and the exposure dose was evaluated using RESRAD6.5[6] developed by US EPA. In this evaluation, the ratio of the radioactive cesium isotopes is ^{134}Cs:^{137}Cs = 1.1:1.0. In addition, the average rainfall and wind speed have been taken from the annual statistics of Fukushima and the other parameters are referenced to the default values of RESRAD6.5 and the Standard of Atomic Energy Society of Japan[7].The main calculation parameters are shown in Table 6.

Fig.6 show the result of external exposure assessment for radioactive Cesium and Fig.7 show the result of the inhalation exposure assessment for radioactive Cesium. In this inhalation exposure assessment, it should be noted that inhalation exposure to radioactive material immediately after the accident has not been included.

5. Conclusion

(1) The situation of the radioactive plume on 15th March, 2011

The presence of the radioactive plume on 15th March due to 1F accident was confirmed. It has been estimated that the radioactive plume on the early morning of 15th March has passed through Ibaraki, Chiba Prefecture from Pacific Ocean and by way of Tokyo bay to Kanagawa, Shizuoka Prefecture. In this case, some of the radioactive plume was deposited on tea plantations due to the presence of morning dew.

In addition, in Bunkyo-ku, Tokyo, the peak of the radioactive plume by the dry ventilation event of 1F Unit 2 was observed at 10:05 am.

In Ono-machi, Fukushima Prefecture, the radioactive plume was observed at around 11 am on 15th March and the dose rate of 10μSv/h was observed at 12:30 pm. This is believed to be the plume emitted from the hydrogen explosion that occurred at 6:10 am and was subsequently released from 1F Unit 2.

(2) Dose assessment by soil deposition of radioactive Cesium

Dose assessment by soil deposition of radioactive Cesium was performed using MCNP and RESRAD based on radiation dose rate measurements; inhalation exposure of radioactive Cesium has been rated as reducing to less than one tenth in the next 10 years.

Reference

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3) Shizuoka prefecture HP, Measurements Report of Radiation Dose Rate 2011.3.15 http://www.pref.shizuoka.jp/kinkyu/1fmonitoring/documents/110311-0831-1fruikei.pdf
4) Ibaraki prefecture HP, Measurements Report of Radiation Dose Rate http://www.houshasen-pref-ibaraki.jp/file/20110311-24hokota.pdf
5) MCNP Manual, X-5 Monte Carlo Team, “MCNP – A General N-Particle Transport Code, Version 5” Volume I: Overview and Theory, LA-UR-03-1987 (April, 2003).
6) RESRAD 6.5:Code System to Implement Residual Radioactive Material Guidelines
7) AESJ-SG-F007:2006, Atomic Energy Society of Japan, Standard Method for Safety Assessment of Disposal of Very Low Level Radioactive Waste:2006

Table 1 Monitoring data at northern part of Tohoku Expressway on 16thMarch, 2011

Place (SA=service area)	Time	1cm dose equivalent rate (μSv/h)
Iwateyama SA	14:00	0.05-0.07
Maezawa SA	15:55	0.05-0.06
Choujahara SA	17:30	0.08-0.09
Kunimi SA	19:15	2.0
Fukushima city	21:00	7-8

Table 2 Radiation monitoring data at the park in Fukushima on 8th April, 2011

Place	City	1cm dose equivalent rate At 1m height (μSv/h)
Kasumigajou park	Nihonmatsu	2.82
Exercise park	Motomiya	3.73
Kaiseizan park	Kohriyama	3.22

Table 3 Radiation monitoring data(surface) at Tokyo area on 17thApril, 2011

Place	Time	Absorbed dose rate (μGy/h)	Place	Time	Absorbed dose rate (μGy/h)
Toranomon	14:53	0.12	Kasumicho	15:34	0.11
USA Embassy1	14:55	0.12	Arisugawa park	15:41	0.08
USA Embassy2	15:01	0.14	Mita Ninohashi	15:52	0.09
Tameike cross	15:06	0.14	Siba park	16:07	0.10
Sanou temple	15:11	0.13	Hibiya park	16:24	0.11
Diet	15:20	0.12	Ueno Shinobazu	16:49	0.12
Toyokawa-inari	15:27	0.12	Sendagi	16:57	0.11

Table 4 Radiation monitoring data(surface) at Johban-Banetsu Expressway on 14th -15th May, 2011

Place (PA=parking area)	Time	1cm dose equivalent rate Surface (μSv/h)
Chiyoda PA	5/14 11:54	0.34
Tano PA	5/14 12:30	0.32
Yunotake PA	5/14 13:36	0.67
Sashio PA	5/15 16:00	0.51
Yunotake PA	5/15 16:25	0.71
Sekimoto PA	5/15 17:00	0.42
Yatabe Higashi PA	5/15 18:30	0.34

Table 5 Calculation conditions of MCNP5

Source geometry	100m×100m×1cm	
Medium of source	Soil	1.73 g/cm^3
Medium under source	Soil	1.73 g/cm^3
Medium above source	Air 1.2E-3 g/cm^3	sphere 1000m
Gamma energy (intensity)	Cs-134	0.56932 (15.43%)
		0.60470 (97.6%)
		0.79585 (85.4%)
		0.80193 (8.73%)
	Cs-137	0.66165 (85.0%)
Library	mcplib04	
Detector	Ring detector	
History number	1E8	(relative error <0.05)

Table 6 Calculation parameter of RESRAD6.5

DCF's for external ground radiation, (μSv/y)/(Bq/g)	Ba-137m (Source: FGR 12)	9.746E+02
	Cs-134 (Source: FGR 12)	2.56E+03
	Cs-137 (Source: FGR 12)	2.03E-01
Dose conversion factors for inhalation, (μSv/Bq)	Cs-134	2.30E-02
	Cs-137+ Ba-137m	4.20E-02
Area of contaminated zone (m^2)	1.00E+08	
Thickness of contaminated zone (m)	1.00E-02	
Average annual wind speed (m/sec)	3.20E+00	
Precipitation (m/y)	1.166E+00	
Cover depth (m)	0	
Fraction of time spent outdoors	7.00E-01	

Fig.1　Time variation of dose rate at Bunkyo-ku,Tokyo on 15th March, 2011

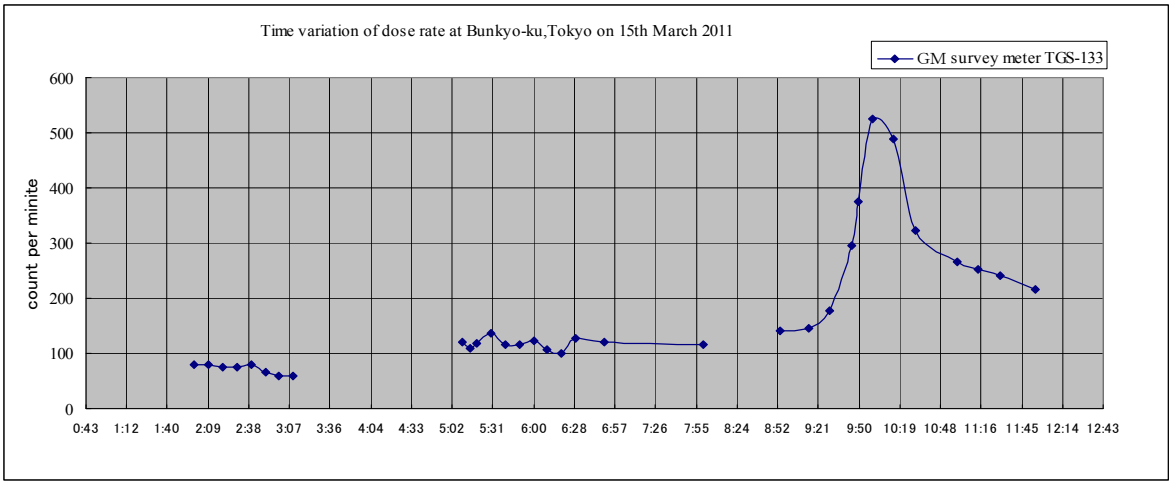

Fig.2　Radiation monitoring data of the southern part of Fukushima and Tochigi prefecture near Tohoku Expressway on 2nd and 3rd April, 2011

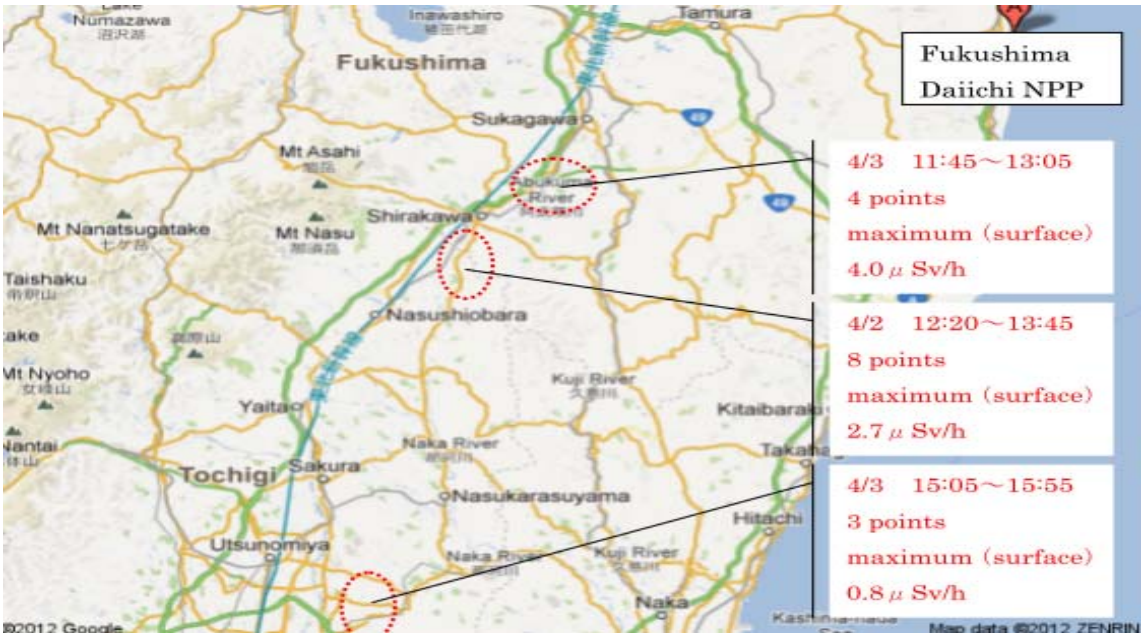

Fig.3　Schematic procedure of exposure evaluation from soil deposition

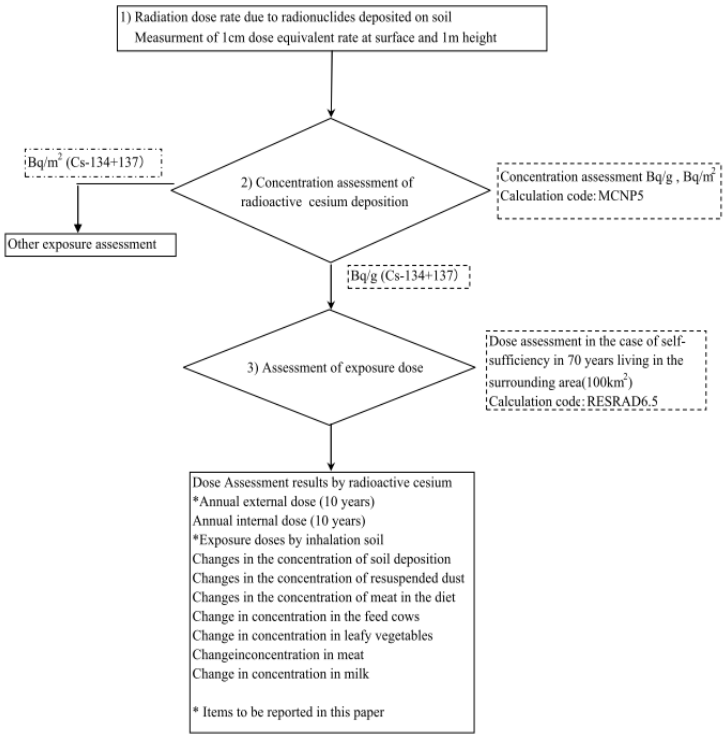

Fig.4　Contour map for 1cm dose equivalent rate at 1m height
(The area about 100m*100m in 8km away west of Fukushima Station JR)

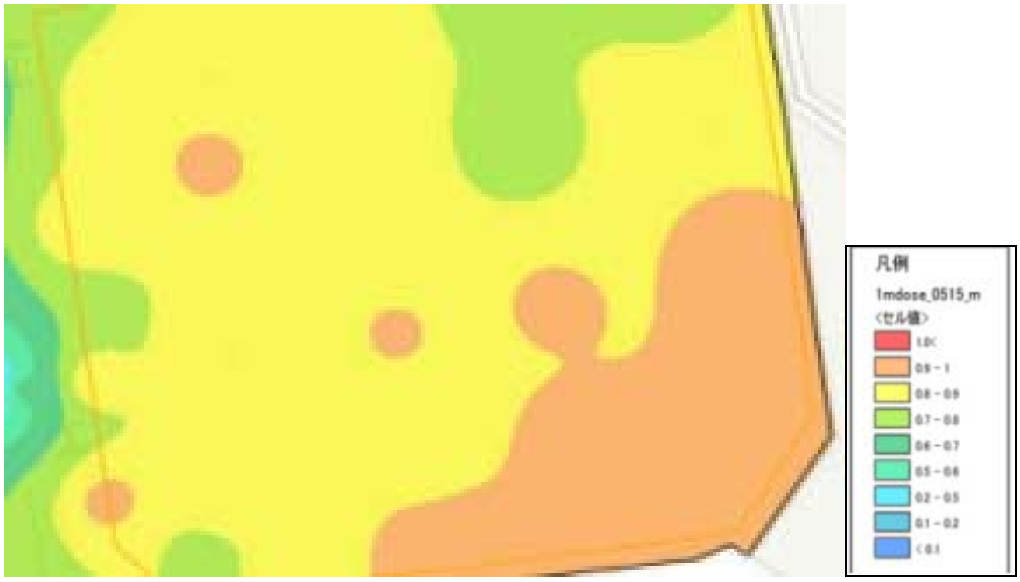

Fig.5 Estimation of soil deposition for radioactive Cesium concentration by MCNP5

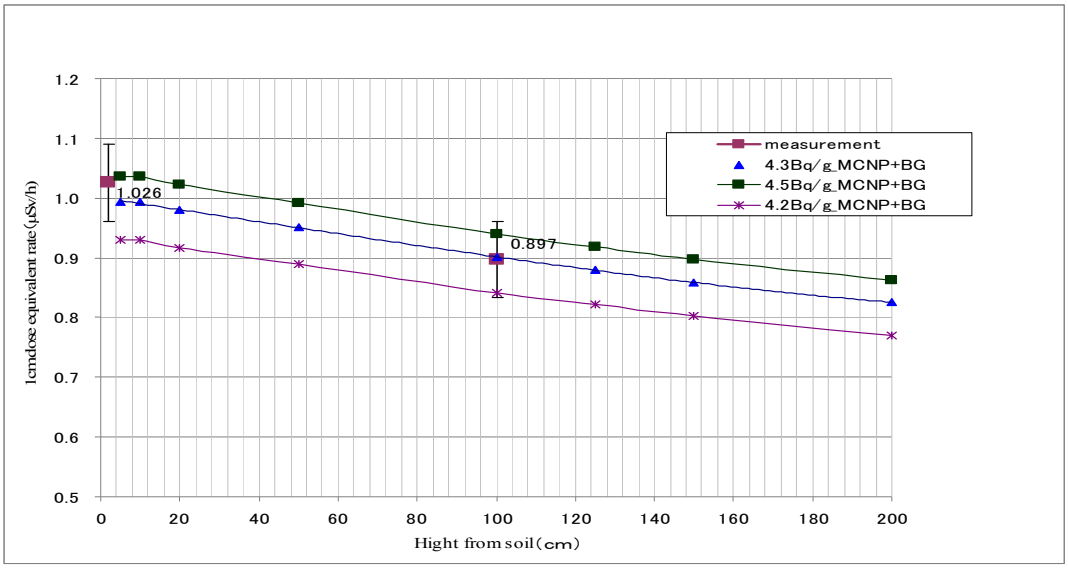

Fig.6　The result of external exposure assessment for radioactive Cesium

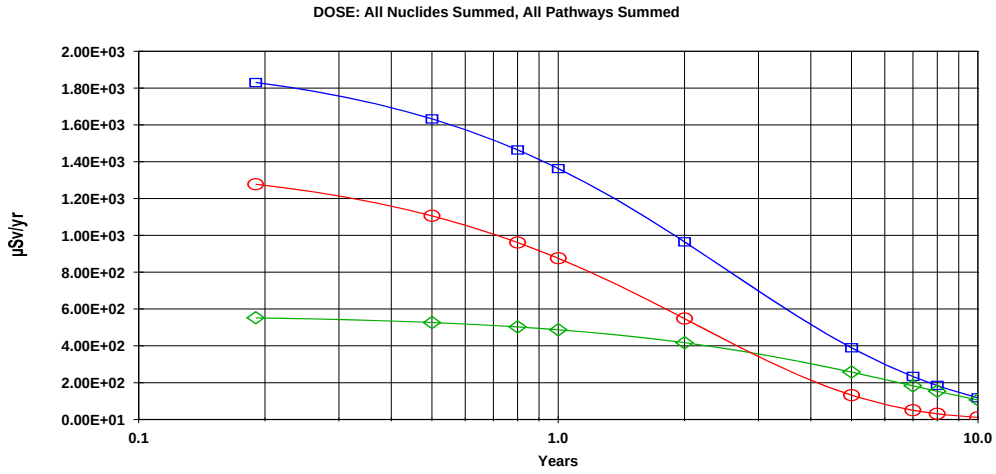

Fig.7　The result of the inhalation exposure assessment for radioactive Cesium