HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2020 Vol.9, No.2 84–92

REM
Radiat Environ Med

Note

An Alternative Approach to Background Radiation Monitoring Using Smartphone-coupled Personal Dosimeter POLISMART in Shimokita Peninsula, Japan

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Received 21 February 2019; revised 31 January 2020; accepted 19 May 2020

Since the Fukushima Dai-ichi Nuclear Power Plant accident in 2011, background radiation dose monitoring was increased throughout Japan for public assurance. In Shimokita Peninsula of Aomori Prefecture, several nuclear-related facilities are present. Background radiation monitoring data within nuclear facilities or selected residential areas in larger cities, measured by nuclear facilities or government agencies, is publicly available. To increase public involvement in radiation monitoring and encourage communication during non-emergency periods, a regional radiation monitoring project in places involved in radiation emergency response was launched in 2015. Background dose rate monitoring using personal dosimeter PM1904A POLISMART® II of four healthcare facilities and one municipal city office in Mutsu City and Higashidori Village determined the baseline level of outdoor background radiation from 2015 to 2018, which was an average of 0.0499 ± 0.011 μSv/h. Temperature, humidity, wind speed, accumulated snow and precipitation did not significantly affect dose rates measured with POLISMART. Although background dose rates measured by POLISMART were higher than those measured by monitoring posts and other detectors in similar locations and measurement periods, annual background radiation calculated from POLISMART measurements was lower than Japan's estimated average of 0.7 mSv/yr. From these results, POLISMART may be additionally used for environmental radiation monitoring and public education.

Key words: Radiation monitoring, public, PM1904A POLISMART® II, Shimokita Peninsula

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1. Introduction

Since the Fukushima Dai-ichi Nuclear Power Plant accident after the Great East Japan Earthquake in March 2011, Fukushima Prefectural Government and Tokyo Electric Power Company Holdings (TEPCO) continuously share radiation monitoring data online to assure the public that background radiation levels are within safe levels. These data are measured in real-time with monitoring posts installed around residential areas and nuclear facilities[1, 2]. Background dose rates are also measured and regularly updated online in other densely populated areas of Japan such as Tokyo[3].

More than 390 km north of Fukushima Prefecture, Shimokita Peninsula in Aomori Prefecture has four nuclear-related facilities: Higashidori Nuclear Power Plant (NPP) (out of service since 2011), Oma NPP (currently building, estimated period of completion in 2021), a nuclear fuel reprocessing facility in Rokkasho and an intermediate nuclear waste storage facility managed by the Recyclable-Fuel Storage Company in Mutsu City (Fig 1, yellow). The sharing of radiation monitoring data in Shimokita Peninsula is hence necessary for public awareness and assurance for residents living nearby. Monitoring posts installed by the Japanese Nuclear Regulation Authority and private companies in charge of nuclear facilities report real-time background dose rates online around residential areas[4], Higashidori NPP[5] and the nuclear waste reprocessing facility in Rokkasho[6]. The data is also nicely summarized in a local magazine published four times annually[7]. As the current strategies for radiation monitoring in Shimokita Peninsula involve larger organizations, one method of improving radiation monitoring is to involve the public in measurement and data collection, which could help in radiation understanding.

The topic of radiation was removed from compulsory public school education in Japan in 1977[8], despite the promotion and construction of NPPs as part of the Atomic Energy Basic Act in 1955[9]. Radiation education was eventually included in the curriculum guideline by the Ministry of Education, Culture, Sports, Science and Technology in 2008[10], and the final curriculum was established for elementary, middle and high school students before the Fukushima Dai-ichi NPP accident in 2011[11]. Detailed descriptions about the accident were then supplementary added in 2014[12] and revised in 2018[13]. As a result, a large proportion of the Japanese population did not receive any compulsory education about radiation. The teaching materials published in 2014, meant for elementary to high school students, were also not easily understood by university students in dentistry[14]. Public participation in previous exercises of radiation monitoring also showed enrichment in radiation education[15], enhanced public awareness to environmental monitoring[16], increased data transparency about radiation measurements[17] and allowed the public to take ownership of radiation protection[18].

Fig. 1. Nuclear-related facilities, nuclear power plants (NPP) (yellow) and POLISMART measurement locations (white) in Shimokita Peninsula, Aomori, Japan (Image obtained from Google Maps, accessed on 2020 Jan 17).

In our study, we analyzed the use of smartphone-coupled personal dosimeters for radiation monitoring in a select group of staff involved in radiation emergency medicine response. As part of the collaboration between Mutsu General Hospital and Hirosaki University Graduate School of Health Sciences in 2015, a simple-to-use background radiation monitoring system in five locations of four healthcare facilities and one municipal city office (Fig 1, white), associated in the local nuclear emergency preparedness and response in Mutsu City and Higashidori Village, was set up. The major goal of this exercise was to familiarize municipal office and clinic staff with background dose rate measurements and basic data analysis. In addition, it encouraged communication between different facilities during non-emergency periods as the surrounding clinics and Mutsu City Office reported to Mutsu General Hospital for data compilation and monitoring equipment rental. Preliminary radiation monitoring results were published previously in 2017[19]. Small, smartphone-coupled personal dosimeters PM1904A POLISMART® II[20] were used to record background radiation dose rates every week for 3 years. These dosimeters are able to detect gamma radiation with Geiger-Müller (GM) tubes and report personal dose equivalent rates (DER in POLISMART manual, $H_p(d)$ rate in ICRP publication 103) in μSv/h. Personal DER

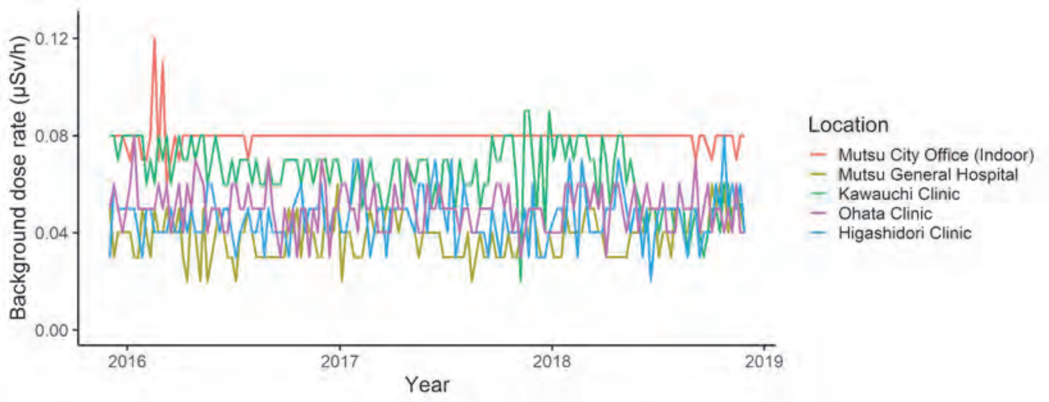

Fig. 2. Background dose rates (μSv/h) measured from Dec 2015 to Nov 2018 of Mutsu City Office, Mutsu General Hospital, Kawauchi Clinic, Ohata Clinic and Higashidori Clinic. Radiation measurements were performed outdoor except for Mutsu City Office, which was performed indoor.

is defined as dose equivalent rate in soft tissue at an appropriate depth d in a human body below the position where an individual dosimeter is worn[21]. DER indication range of POLISMART was reported as 0.01 to 120.0 μSv/h.

This study (i) compiles background radiation monitoring data measured in three years with POLISMART in five locations involved in radiation emergency preparedness in Shimokita Peninsula, (ii) evaluates possible effects caused by different weather parameters on POLISMART dose rate measurements and (iii) summarizes background radiation measurements with POLISMART and monitoring posts or other detectors in similar locations and time period.

2. Materials and Methods

Radiation monitoring equipment

Background dose rate monitoring in μSv/h was performed with electronic personal dosimeter PM1904A POLISMART® II (Polimaster, Belarus, Russia) and a smartphone with the associated application installed. According to the manufacturer's manual, the detector was calibrated with 0.662 MeV gamma rays emitted from ^{137}Cs. It can detect gamma rays of 0.059 to 1.5 MeV with its GM tube.

Radiation monitoring period and locations

Detailed methodology was previously published in Japanese[19]. Background dose rate was measured every Wednesday at around 8.30 to 9 am from December 2015 to November 2018. Measurements were performed at the same spot in Mutsu City Office, Mutsu General Hospital, Kawauchi Clinic, Ohata Clinic and Higashidori Clinic. The locations and team involved in radiation monitoring were decided by Mutsu General Hospital and Mutsu City Office based on the communication of medical information within medical facilities in Mutsu City and Higashidori Village. Staff involved in radiation measurements were trained with representatives from Polimaster Japan Inc (Kanazawa, Japan). Polimaster Japan Inc ensured and maintained the quality of POLISMART measurements, and was available for any device troubleshooting. Measurements were only recorded after multiple stabilized readings were obtained after a minimum of 30 seconds wait, taken at a height of around 1 m above the ground and performed outdoor for all locations except for Mutsu City Office. Data from the individual locations were compiled by the team in Mutsu General Hospital and sent to Hirosaki University for detailed analysis.

Weather data

Weather data (temperature, humidity, wind speed, accumulated snow and precipitation) was obtained from the Japan Meteorological Agency[22] at 9 am for each measurement date. The weather station is in Mutsu City, 2.9 m above ground, located at 41.283333, 141.210000 in decimal degrees.

Statistical tests

Data representation and statistical analyses were carried out with R ver 3.6.2[23], RStudio ver 1.2.5033[24] and an additional package of "tidyverse"[25]. Correlation was examined with non-parametric Spearman's rank correlation coefficient. p values < 0.05 were considered to be significant. Dose rates were reported as Mean ± SD.

3. Results

Radiation monitoring over a three-year period with POLISMART

Background radiation dose rates measured by POLISMART of five locations in Mutsu City and Higashidori Village is

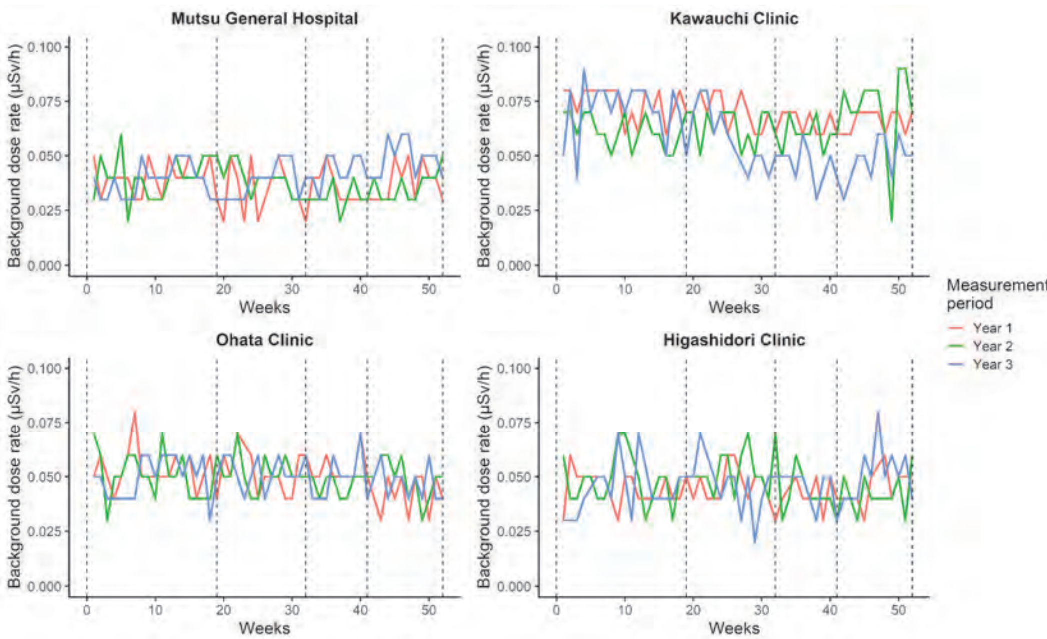

Fig. 3. Outdoor background dose rates (µSv/h) of each annual period from December of the previous year to November next year. Periods representing winter (weeks 0 to 18), spring (weeks 19 to 31), summer (weeks 32 to 40) and autumn (weeks 41 to 52) were marked in each graph. Year 1 was from Dec 2015 to Nov 2016; Year 2 was from Dec 2016 to Nov 2017; Year 3 was from Dec 2017 to Nov 2018.

shown in Figure 2. The three-year-averaged background dose rates and their standard deviations of Mutsu City Office (Indoor), Mutsu General Hospital, Kawauchi Clinic, Ohata Clinic and Higashidori Clinic were 0.0797 ± 0.005 µSv/h, 0.0391 ± 0.009 µSv/h, 0.0641 ± 0.013 µSv/h, 0.0501 ± 0.009 µSv/h and 0.0463 ± 0.010 µSv/h respectively. Background dose rates were mostly consistent in the five locations throughout the three-year-period, except for the spike seen in Mutsu City Office.

Analysis of weather parameters and background radiation rates measured with POLISMART

To investigate if background dose rate measurements were seasonally affected, outdoor background dose rates of Mutsu General Hospital, Kawauchi Clinic, Ohata Clinic and Higashidori Clinic were split up annually (Fig 3). In general, weeks 0 to 18 represent winter, weeks 19 to 31 represent spring, weeks 32 to 40 represent summer and weeks 41 to 52 represent autumn. Background dose rates appeared to be relatively stable despite the change in seasons.

As detailed weather data was only available in the center of Mutsu City, outdoor background radiation rates of Mutsu General Hospital were used to analyze the possible effects of temperature, humidity, wind speed, accumulated snow and precipitation. Figure 4A shows temperature, humidity and wind speed changes compared to the background radiation rates of each year. Figure 4B shows changes in accumulated snow compared to the background radiation rates measured in the winter of each year. Figure 4C shows precipitation measured at each measurement date, in comparison to background radiation rates of the entire measurement period. No significant correlation was seen between background dose rate and each weather parameter (Temperature vs Dose rate: ρ = -0.105, p = 0.199; Humidity vs Dose rate: ρ = -0.010, p = 0.903; Wind speed vs Dose rate: ρ = 0.023, p = 0.781; Accumulated snow vs Dose rate: ρ = -0.142, p = 0.301; Precipitation vs Dose rate: ρ = 0.077, p = 0.511).

Summary of background radiation dose rates measured by POLISMART and other detectors

In addition, background radiation dose rate measurements using POLISMART and other detectors in similar locations and periods of measurements were compiled in Table 1. Radiation dose rates detected by POLISMART were overall higher than those measured by other monitoring posts and detectors.

4. Discussion

Background radiation monitoring in Shimokita Peninsula is currently managed by the government and companies involved in nuclear energy and nuclear waste recycling. As compared to other densely populated cities in Japan, Shimokita Peninsula has a large area of 1,876.82 km^2 with

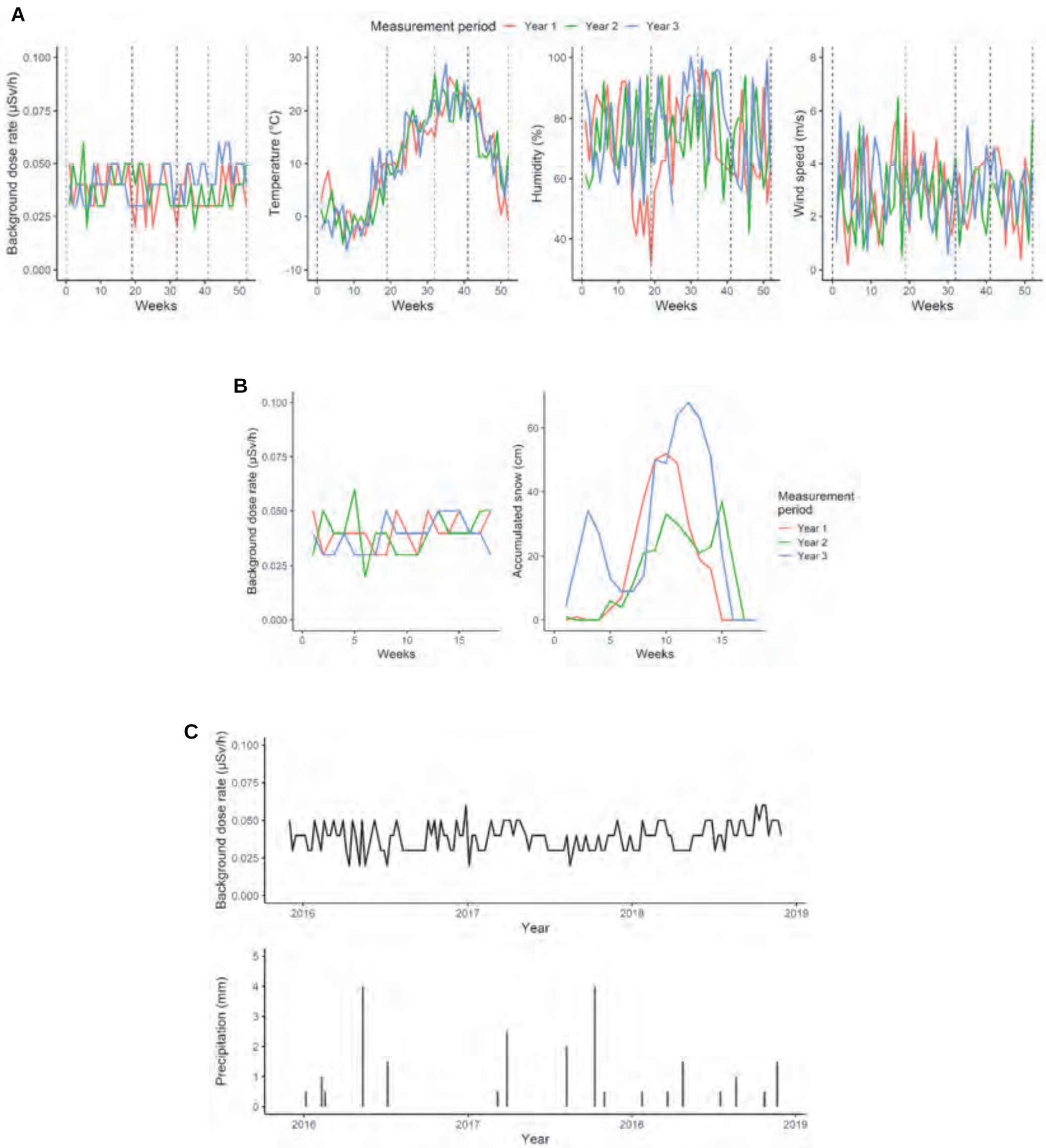

Fig. 4. Changes in weather parameters and outdoor background dose rates of Mutsu General Hospital (µSv/h). (A) Temperature, humidity and wind speed changes compared to background dose rates measured each year. (B) Accumulated snow changes compared to background dose rates measured in the winter of each year. (C) Precipitation changes compared to background dose rates measured for the entire period.

96,182 residents[28], with most of the residents living in Oma, Mutsu Central, Kawauchi Town and Ohata Town. As a result, radiation monitoring and reporting tend to be concentrated in those residential areas. However, current radiation monitoring efforts in Shimokita Peninsula can be improved by increasing public involvement. In our study, we analyzed the effectiveness of electronic personal dosimeter POLISMART for background radiation monitoring among locations involved in radiation emergency response in Mutsu City and Higashidori Village. The people involved in monitoring were healthcare professionals and government workers trained in POLISMART measurement and briefed on the importance of background radiation monitoring.

The three-year measurement of background dose rates in Mutsu City and Higashidori Village showed relatively stable values in the four outdoor locations, with an average of 0.0499 ± 0.011 µSv/h. Indoor readings in Mutsu City Office were higher, with an average of 0.0797 ± 0.005 µSv/h, and a spike seen of up to 0.12 µSv/h. As explained previously[19], the spike was most probably a measurement error as the nearest nuclear facility in Higashidori was not in service. Nevertheless, the annual average outdoor background dose measured by

Table 1. Comparison of background radiation rates measured with POLISMART and other radiation detectors around residential and nuclear facilities in Shimokita Peninsula, Aomori Prefecture.

Detector	Measurement period	Location (Co-ordinates)	Background radiation (μSv/h)
POLISMART	Dec 2015 – Nov 2018	Mutsu General Hospital (41.293687,141.201687)	0.0391 ± 0.009
		Mutsu City Office (41.292562,141.182563)	0.0797 ± 0.005 (Indoor)
Monitoring post[a]	Dec 2015 – Nov 2018	Kogawamachi (41.289440,141.216940)	0.0161 ± 0.001
Na-I (TI) Aloka TCS-171B[b]	2 Nov 2015	Asahimachi Jido Park (41.287312,141.177812)	0.03
POLISMART	Dec 2015 – Nov 2018	Kawauchi Clinic (41.200812,140.986188)	0.0641 ± 0.013
Monitoring post[a]	Dec 2015 – Nov 2018	Kawauchi City Office (41.195813,140.997563)	0.0221 ± 0.002
RPLD[c]	Apr 2014 – Mar 2015	Kawauchi Nakamichi (exact location unknown)	0.0458 (401 μGy/365 d)
POLISMART	Dec 2015 – Nov 2018	Ohata Clinic (41.399688,141.158312)	0.0501 ± 0.009
Monitoring Post[a]	Dec 2015 – Nov 2018	Sekine (41.358812, 141.204563)	0.0220 ± 0.002
RPLD[c]	Apr 2014 – Mar 2015	Sekine (exact location unknown)	0.0435 (381 μGy/365 d)
POLISMART	Dec 2015 – Nov 2018	Higashidori Clinic (41.276687,141.337438)	0.0463 ± 0.010
Monitoring post[a]	Dec 2015 – Nov 2018	Sunagomata (41.279813,141.329313)	0.0212 ± 0.001
Na-I (TI) Aloka TCS-171B[b]	12 Nov 2015	Higashidori Village (41.222687,141.397563)	0.028
Monitoring post[d]	17 Jan 2020, 1420h	Higashidori NPP (41.188188,141.390438)	0.0148 ± 0.002
Monitoring post[e]	17 Jan 2020, 1520h	Rokkasho Nuclear Waste Reprocessing Facility (40.956562,141.325188)	0.0161 ± 0.001
Monitoring post[f]			0.0210 ± 0.002

Data is presented as Mean ± SD where necessary.
Location co-ordinates are presented as their latitude and longitude GPS co-ordinates in decimal degrees.
Background radiation rates were measured outdoors unless otherwise stated as indoor.
Radiation dose rates measured in nGy/h were converted to μGy/h and treated equivalent to μSv/h.
[a] Monitoring posts installed and maintained by Aomori Prefectural Government, as part of the Japanese Nuclear Regulation Authority[4]. Averaged background radiation rates of each month from Dec 2015 to Nov 2018 were used for calculation.
[b] Readings taken from the 2016 report published by the Aomori Prefectural Nuclear Safety Center[26].
[c] Readings from environmental radiation monitoring performed by Aomori Prefectural Nuclear Safety Center and the Recyclable-Fuel Storage Company in Mutsu City[27].
[d] Real-time radiation monitoring data averaged from monitoring posts MP-1 to 8 in Higashidori NPP[5]. Readings taken at 17 Jan 2020, 1420h.
[e] Real-time radiation monitoring data averaged from monitoring posts MP-1 to 9 in the reprocessing facility in Rokkasho[6]. Readings taken at 17 Jan 2020, 1520h.
[f] Real-time radiation monitoring data averaged from monitoring posts MP-1 to 3 in the uranium enrichment and low-level radioactive waste storage in Rokkasho[6]. Readings taken at 17 Jan 2020, 1520h.

POLISMART (0.437 ± 0.092 mSv/year) was below the estimated annual average external background dose rate from terrestrial and cosmic radiation in Japan of 0.7 mSv/year[29].

Different weather conditions may also affect the accuracy of background radiation measured by POLISMART and other detectors. There are well-documented studies showing a positive correlation between precipitation and elevated background radiation, caused by radionuclide scavenging effects of rainfall or snow[30]. In addition, a local study by the Aomori Prefectural Nuclear Power Safety Center showed a negative correlation of background dose measured with both NaI (TI) survey meters and passive personal radiophotoluminescence dosimeters (RPLD) with increasing accumulated snow of 0 to 120 cm[31]. A decrease of background gamma radiation measured with NaI (TI) survey meters with accumulated snow of 35 to 60 cm was also shown in a previous study performed in Shiga Prefecture[32]. However, our results showed no significant correlation between changes in weather elements (accumulated snow and precipitation) and background radiation rate. One reason could be the lower gamma ray detection efficiency of the GM tube in POLISMART, resulting in its inability to detect minute changes in gamma radiation. It could also be attributed to the lack of accumulated snow at Mutsu General Hospital, as snow is usually cleared by shoveling or heated floors for easy public access.

Furthermore, official or government-approved background radiation monitoring in Japan frequently utilize larger real-time detectors in monitoring posts and systems or passive personal dosimeters. On the other hand, active portable personal dosimeters for radiation monitoring is often for personal use. In response to the Fukushima NPP accident in 2011, a team in Japan developed self-contained GM counter devices with internal storage and GPS called Safecast[17], which can be used with and without a smartphone. Measurements performed by the public can be uploaded on the dedicated map at their website. These measurements are currently only concentrated in Fukushima and scattered around Japan, but no such recordings in Shimokita Peninsula have been reported[33]. Radiation-watch, developed in Japan, also offers portable smartphone-coupled GM counters with a compatible application to store and report data in counts/min, μSv/h and GPS co-ordinates[34]. Other companies have also developed their own portable radiation detectors, such as OpenRadiation by four French organizations[35], DO-RA dosimeter by JSC Intersoft Eurasia[36] and GammaGuard by Environmental Instruments Canada Inc[37]. Various smartphone applications have also been created to use built-in cameras as sensors, such as GammaPix by Image Insight Inc[38] and RadioactivityCounter by Helmholtz Zentrum München[39]. The detection accuracy may be compromised depending on the type of camera lens, angle of the camera, camera lens coverage with black tape and/or aluminum foil, temperature of the environment and device, and algorithm for noise removal[18].

When comparing the values of background radiation detected, our measurements with POLISMART showed consistently higher background radiation rates as compared to conventional monitoring equipment. Measurements from Safecast in Minami-Soma, Fukushima also reported a higher value (0.141 μSv/h, 23 Mar 2020, 1748h)[40] than measurements performed by a monitoring post installed by the Fukushima Prefectural Government (0.111 μSv/h, 23 Mar 2020, 1750h)[41]. Similarly, measurements from OpenRadiation in Central Paris reported higher values (0.02 to 0.19 μSv/h, 12 Aug 2019)[42] than government-reported measurement with telemetry sensors (0.06 μSv/h, 12 Aug 2019)[43]. Passive personal dosimeters also showed higher background radiation (GD-450: 0.10 μSv/h, Luxel: 0.14 μSv/h, DIS: 0.10 μSv/h)[44] as compared to the averaged values from real-time monitoring posts (0.06 μSv/h)[45] in Kanazawa City. Thus, it seems background radiation rates measured with personal dosimeters tend to be higher than monitoring posts and survey meters. Differences in detection efficiency, type of radiation detected and how counts/min is converted to μSv/h are likely reasons for the discrepancy.

A preliminary survey conducted by the SHAMISEN-Stakeholder INvolvment in Generating Science (SHAMISEN-SINGS) project in September 2018 showed 75 % of higher education (University, PhD level) responders were more aware of the traditional dosimeters (RPLD, GM counter) than devices or applications developed independently for radiation monitoring (Safecast, POLISMART, DO-RA etc). However, in survey respondents from Ukraine and Belarus, more than 77% of them knew the existence of such devices and applications[18], possibly due to their proximity to Chernobyl NPP and the increased radiation monitoring performed. This once again highlights the importance of education and increasing public awareness to all available options for a public-based monitoring system for radiation emergency and preparedness, especially for those living near nuclear facilities. Furthermore, to encourage the use of such devices or applications for public radiation monitoring, developers need to account for portability, affordability, accessibility, battery consumption, ease of use, and detection reliability and accuracy. Additionally, as most novel devices are calibrated with known radioactive sources such as ^{60}Co and ^{137}Cs, validation of such devices with background dose is rarely performed[18]. To further improve on our study, simultaneous measurements of both Na(I) TI survey meter and POLISMART will be performed for validation, and for the monitoring locations to be extended to Oma.

In conclusion, the use of POLISMART for a regional dose monitoring system in locations involved in radiation emergency preparedness provided an additional opportunity for healthcare professionals and local government officials to actively participate in radiation monitoring and communicate during non-emergency periods. By understanding the importance of background radiation monitoring, the responders would be better equipped to deal with radiation emergencies[46]. Despite higher background dose rates reported by POLISMART, the overall annual background radiation was lower than the expected 0.7 mSv/year. In addition, there is an increasing interest to encourage the general public to be involved in radiation monitoring with dosimeters and smartphones[18], which is especially important to those living near nuclear facilities. With such benefits, POLISMART may be used additionally for radiation monitoring, public awareness and education in Shimokita Peninsula.

Acknowledgements

We would like to extend our gratitude to Masaru Tokuda, Kazuo Watanabe and Mitsuhiko Okugawa for their contribution to the daily measurements of background

dose rate.

Funding

This work was funded by Aomori Brand Research.

Conflict of Interest

The authors report no conflicts of interest. The authors alone are responsible for the contents of the paper.

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