HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2019 Vol.8, No.1 1–8

REM
Radiat Environ Med

Regular Article

# Assessment of Safecast bGeigie Nano Monitor

Joshua Walsh*, Kevin Kelleher and Lorraine Currivan

*Environmental Protection Agency, 3 Clonskeagh Square, Clonskeagh Road, Dublin 14, Ireland*

Received 2 February 2018; revised 25 June 2018; accepted 20 August 2018

The bGeigie Nano Monitor is a radiation monitor based on a Geiger Muller tube (GM) detector developed by the team at Safecast as an affordable and easy to use mobile radiation monitoring device for public use as part of its citizen science project. The bGeigie Nano Monitor is said to detect alpha, beta and measure gamma radiation accurately to within a 15% uncertainty, as well as the ability for this measured data to be uploaded to a Safecast API website. The objective of this study was to evaluate the bGeigie Nano Monitor's accuracy and reliability in both measuring and recording radiation from alpha, beta and gamma sources.

It was found that the bGeigie Nano Monitor is very accurate in the dose rate range of 5-900 μSv/h. Above this dose rate the accuracy of the measurements were not as reliable as the monitor was brought closer to the 1000 μSv/h limit of detection. The monitor was capable of detecting beta and gamma radiation from the tested sources of $^{241}$Am, $^{90}$Sr/$^{90}$Y and $^{137}$Cs. During the assessment of the monitor it was found that it could take up to a minute for the measured dose rate exposed to a source to stabilise, it was also found that after being exposed to a high dose rate it took up to a minute to return to background dose levels after the removal of the radiation source.

In conclusion, the bGeigie Nano Monitor is capable of being an easily assembled radiation monitor for the public to accurately measure the dose rates of radioactivity in their area and to share this monitoring data through the Safecast API website.

*Key words:* Safecast, radiation monitor, citizen science

## 1. Introduction

Safecast is a volunteer centred group that is involved internationally in supporting and furthering open data and citizen science projects, particularly in the environmental field. The Safecast organisation was set up after the Fukushima Daiichi Nuclear Power Plant disaster, which occurred in Japan on the 11th of March 2011 due to an earthquake linked tsunami which caused the power plant do go into meltdown[1]. With the lack of available and accurate data on the levels of radiation leaking from the nuclear power plant, Safecast was set up to measure and report the findings so that the public could be informed of the risks they were facing. The aim of Safecast now is to allow the public, through its citizen science projects, access to accurate and easy to use tools that will both measure and record radiation and pollutant levels in the air[1]. One of these tools for public use in measuring and recording ionising radiation dose rates is the bGeigie Nano Monitor (Fig. 1). It is an easily assembled radiation GM that the public can use to measure the dose rates of ionising radiation in their area and share this monitored data through the API website[1].

In Figure 2 a map of Japan can be seen, and all the plot points and interpolated data for Japan are based on

*Joshua Walsh : Environmental Protection Agency, 3 Clonskeagh Square, Clonskeagh Road, Dublin 14, Ireland
E-mail: j.walsh@epa.ie


**Fig. 1.** The bGeigie Nano Monitor fully assembled with the case on.

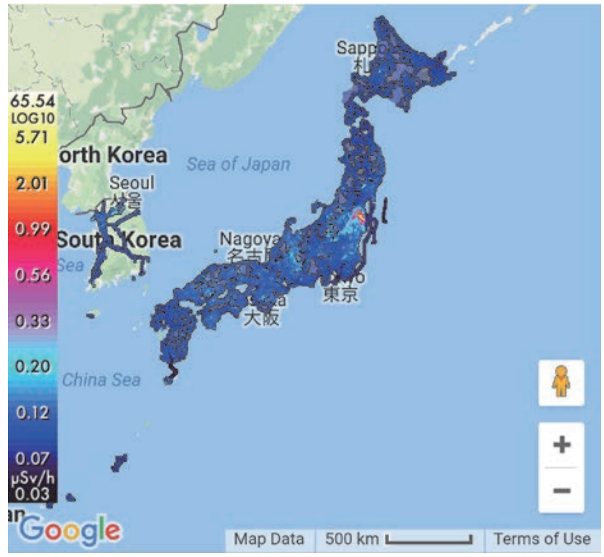


**Fig. 2.** The Safecast API map of Japan taken on the 22/3/17. In this figure, the plot points represent a measurement taken by bGeigie Nano Monitors that have been uploaded to the Safecast website[2]. (http://safecast.org/tilemap/?y=38.7&x=135.1&z=5&l=0&m=0)

measurements taken by bGeigie Nano Monitors.

The purpose of this work is to determine whether the bGeigie Nano Monitor is fit for the purpose and conforms to the standards specified by Safecast, i.e. that is an easy to use and reliable radiation GM for measuring ionising radiation. The performance and reliability of the bGeigie Nano Monitor will be evaluated by testing the monitor in the Environmental Protection Agency's (EPA) calibration facility, which is an ISO 17025 accredited calibration facility that tests and calibrates similar monitors[3], with a $^{137}$Cs source. The reliability of the monitor will also be tested by an inter comparison of measurements with an EPA fixed gamma dose rate monitor "70031A LD-Tube" ENVINET[4]. The bGeigie Nano Monitor is capable of measuring alpha, beta and gamma radiation[5].

The effectiveness of the bGeigie Nano Monitor of measuring beta and gamma radioactivity will be tested using radioactive reference sources used in the EPA. These sources include $^{241}$Am, $^{90}$Sr/$^{90}$Y and $^{137}$Cs. The monitor will also be tested for the stability of its measurements and the time frame needed to acquire these measurements, hence the time required for a stable reading in the presence and removal of an ionising radiation source. All uncertainties referenced/stated are to k = 1 unless otherwise stated.

## 2. Materials and methods

### *2.1. Assembly of the bGeigie Nano Monitor*

The bGeigie Nano Monitor comes in its component parts and costs approximately $600[6]. These are the standard components, but extra accessories such as Bluetooth modules can be bought and installed on the monitor, although this was not done for the purposes of this study. To assemble the monitor, additional components such as soldering equipment, a soldering iron, solder and wire cutters are required. Some experience in soldering electronic components is also required for the monitor to be assembled correctly. The Safecast website gives a very comprehensive guide on how to assemble the monitor[7]. This guide is very easy to follow for novices and experts alike, while also offering tips on some of the more complicated tasks needed to assemble the monitor. The assembly of the monitor was completed over the space of two days and totalled 6 - 7 hours of soldering and assembling the components. Utilising the guide[7] allowed for an easier assembly of the monitor, but experience in this area is necessary and recommended if it is to be assembled in working order. It can be easy to make a mistake on some of the more intricate soldering work and re-soldering these delicate components can damage the circuit board and components. This could render the monitor, at worst, non-functioning. It can also be noted that the LCD screen as well as the GPS slots are printed on to the board to make it much easier to install the components.

### *2.2. Overview of the bGeigie Nano Monitor*

The bGeigie Nano monitor is built for measuring dose rates and count rates of radioactivity; this includes alpha, beta and gamma radiation, and weighs approximately 420g after construction. The dose rate is measured using an LND 7317 Pancake mica window alpha-beta-gamma detector based on a flat cylindrical "Pancake" gas filled Geiger Muller counter[8]. (See Table 1 for the specifications of the LND 7317 Pancake). The bGeigie Nano Monitor has two measurement modes. The first mode is "bGeigie Mode"[5] which will take measurements

**Table 1.** The general specifications for the LND 7317 pancake[8)]

| GENERAL SPECIFICATIONS | |
|---|---|
| Gas filling | Ne + Halogen |
| Cathode material | Stainless Steel |
| Maximum length (inch/mm) | 3.00/76.1 |
| Effective depth (inch/mm) | 0.5/12.7 |
| Maximum diameter (inch/mm) | 2.11/53.6 |
| Effective diameter (inch/mm) | 1.75/44.5 |
| Connector | Grid Cap |
| Operating temperature range ℃ | -40 to + 75 |
| **ELECTRICAL SPECIFICATIONS** | |
| Recommended anode resistor (meg ohm) | 4.7 |
| Maximum starting voltage (volts) | 425 |
| Recommended operating voltage (volts) | 500 |
| Operating voltage range (volts) | 475 - 675 |
| Maximum plateau slope (%/100 volts) | 10 |
| Minimum dead time (micro sec) | 40 |
| Gamma sensitivity Co60 (cps/mR/h) | 58 |
| Tube capacitance (pf) | 3 |
| Weight (grams) | 125 |
| Maximum background shielded 50mm Pb + 3mm Al (cpm) | 30 |
| Minimum anode resistor (meg ohm) | 3.3 |

**Fig. 3.** The back of the bGeigie Nano Monitor with the case off. Also note the LND7317 Pancake GM on the back of the monitor.

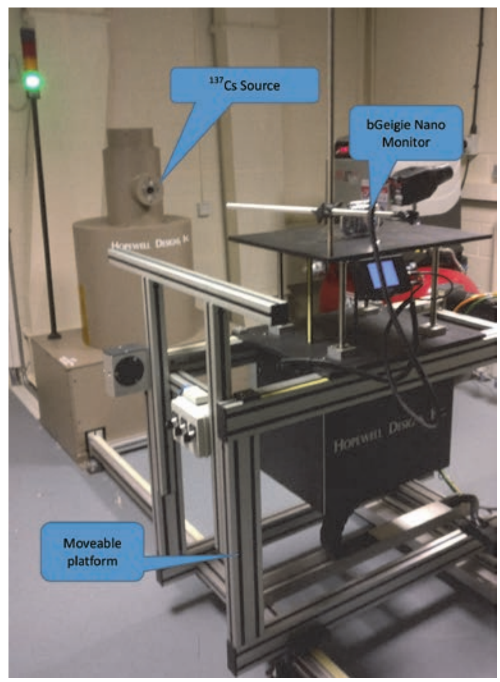


**Fig. 4.** The EPA's calibration facility[3)]. The bGeigie Nano Monitor can be seen attached to the moveable platform which is in the line of sight of the $^{137}$Cs source[9)]

in CPM (counts per minute) every five seconds including the time and location of the measurement if there is a satellite link to the monitor[5)]. This information will be logged to an SD card which is inserted into the SD slot installed in the monitor. This can later be uploaded to the Safecast website or downloaded from the SD card itself once connected to a computer[3)]. The second mode is "xGeigie mode" which gives the primary reading in dose equivalent rate μSv/h. Figures 1 and 3 show the fully assembled bGeigie Nano Monitor from both a front and back view in "bGeigie Mode". In the front view, the LCD screen can be seen displaying the CPM, dose rate, time, date and the battery life of the monitor. The back view of the monitor shows the LND 7317 Pancake GM[8)]. With the case off, the monitor can measure alpha, beta and gamma radiation. However, with the case on, the measurement of alpha and beta radiation is inhibited due to the attenuation of these particles by the solid plastic case.

### *2.3. Calibration Test of the bGeigie Nano Monitor*

The stated operating range of the bGeigie Nano Monitor is 0 – 1,000 μSv/h, Gamma sensitivity of 334 CPM per μSv/h referenced to $^{137}$Cs and 0 to 350,000 CPM[5)]. To determine whether this range was as specified by the bGeigie Nano Monitor, a calibration test was carried out. The test was carried out in the EPA's calibration facility. The EPA provides a calibration service which is accredited by the Irish National Accreditation Board to ISO17025[3)]. The test was carried out using a Hopewell GC60 irradiator with collimated $^{137}$Cs 0.7-1110 GBq (662 keV) sources with an ambient dose equivalent, H*(10) dose range of 5 μSv/h– 220 mSv/h[9)]. The range of the test went from 5 μSv/h to 1200 μSv/h. The calibration test was carried out by fixing the bGeigie Nano Monitor to a platform which ran on a moveable track, as seen in Figure 4. The pancake GM was aligned to the centre of the Hopewell irradiator using a laser pointer. This ensured that the pancake GM was aimed at the collimated $^{137}$Cs source[8)]. A camera was fixed on the face of the monitor to record the measured dose rate. The monitor was set in "bGeigie Mode" so that it was also recording the measurements during the calibration. Five

**Table 2.** The sources used in the response tests

| Source | Manufacturer | Product Code | Emission(s) | Activity (Bq) | ± Uncertainty on activity (Bq) | Reference date |
|---|---|---|---|---|---|---|
| $^{241}$Am | Amersham International plc | AMR.121 | Alpha, Gamma | 36200 | 1810 | 1200 GMT 01/09/1988 |
| $^{90}$Sr/$^{90}$Y | Amersham International plc | SIR.52 | Beta | 18100 | 724 | 1200 GMT 12/08/1985 |

background dose rates measurements were recorded before every measurement. The average of these measurements was then subtracted from the subsequent calibration measurement. The dose rates the monitor was exposed to was varied by adjusting the distance of the monitor on the moveable track from the exposed $^{137}$Cs source[8]. The measurement on the bGeigie Nano Monitor was given time to stabilise before the measurement was recorded. Stable in this instance meant there was very little fluctuation in the value. Once the measurement was stable, six readings were recorded. The source would then be removed and the bGeigie Nano Monitor would be allowed to return to background dose rate levels. Once the dose rate reading on the monitor had returned to background dose rate levels, the next dose rate was tested. The mean of the six measured dose rates was calculated and the average background dose rate was subtracted to get the measured dose rate.

### *2.4. Comparison of Monitors*

To compare the bGeigie Nano Monitor to environmental dose rates that are typical for the south Dublin area, the monitor was set up in a fixed area 1 m above the ground alongside another site monitor that was positioned 1 m above ground level. The monitor used in this inter comparison was calibrated and routinely used by the EPA in field work. The monitor used was the ENVINET "IGS421B-H 70031A LD-Tube"[4] which is the EPA's fixed gamma dose rate monitor. This type of monitor is used at fixed locations where it measures and records the dose rate of its surrounding environment and this data is then sent to the EPA website where the data is made available for public access. There are several of these monitors located around the country measuring dose rates in specific areas.

The comparison took place over a period of 76 hours, where the bGeigie Nano Monitor was set in "bGeigie Mode"[5] taking measurements every five seconds, and the EPA calibrated monitor measurements were recorded every hour in an aggregated form. The time frame of 1 hour was used as this was the time the ENVINET[4] reported measurements. To compare the dose rate measurements of the Safecast monitor with the ENVINET[4] EPA calibrated monitors, a Zeta test[10] (This is a data evaluation test which shows agreement between measurements when taking the value and uncertainties into account, values ranging from 0 – 2 indicate good agreement, 2 – 3 questionable agreement and 3 + shows a lack of agreement.) was carried out on the data recorded by the two monitors. The results of the Zeta test[10] would determine whether there was good agreement between the two monitors as they were in the same area at the same time.

### *2.5. Response of detector to different source types (Beta and Gamma)*

The EPA has radioactive reference sources of known activity. These sources were used to test how the bGeigie Nano Monitor responds to different activity sources and source types. The reason multiple tests were done with different radioactive sources was to test if the monitor would respond differently to other radionuclides apart from $^{137}$Cs, since the monitor mainly measures $^{137}$Cs in its use in Japan. It was also stated that the bGeigie Nano Monitors are calibrated using $^{137}$Cs as a source[5]. The bGeigie Nano Monitor was exposed to the beta and gamma sources outlined in Table 2. The response of the monitor to the sources was taken with the case on and off. The measurements of the beta source emitter was taken when the case was on and off the monitor to check if there was any noticeable difference between measurements which can be attributed to the attenuation of $\beta$ particles by the solid plastic Pelican™ case.

### *2.6. Stabilisation time of detector readings in response to variations in the radiation field*

During the measurements in the calibration facility[3], it was noted that it took time for the measurement of the dose rates above background level to stabilise, meaning high dose rates were taking longer than background measurements to stabilise, and hence, measure accurately over a short time. It was also noted that the same time issue occurred when the $^{137}$Cs source[8] had been removed, meaning it took a long time for the bGeigie Nano Monitor to return to background dose rates after being exposed to high dose rates from the $^{137}$Cs source[8]. To evaluate the time, it took the GM to stabilise during and after the removal of the $^{137}$Cs source[8], the time taken for the monitor stabilise and return to background dose rates in the EPA calibration facility after removal of the $^{137}$Cs

**Table 3.** The calibration data for the bGeigie Nano Monitor. This includes the exposure dose rate of the Hopewell $^{137}$Cs source[10] and the measured activity of the bGeigie Nano Monitor with the uncertainty associated with the monitor as reported by the Safecast website[5]

| Exposed Dose Rate (μSv/h) | Measured Average Dose Rate (μSv/h) | Uncertainty of (±15%) (μSv/h) for the measured average dose | Percentage difference (%) |
|---|---|---|---|
| 5 | 5.2 | 0.8 | +4.0 |
| 30 | 31.7 | 4.8 | +5.6 |
| 50 | 53.1 | 7.9 | +6.2 |
| 100 | 98.3 | 14.7 | -1.7 |
| 300 | 300.3 | 45.0 | +0.1 |
| 500 | 488.8 | 72.7 | -2.2 |
| 700 | 645.0 | 96.1 | -7.9 |
| 800 | 717.3 | 107.6 | -10.3 |
| 900 | 787.1 | 118.1 | -12.5 |
| 1,000 | 838.6 | 125.8 | -16.1 |
| 1,200 | 964.4 | 144.7 | -19.6 |

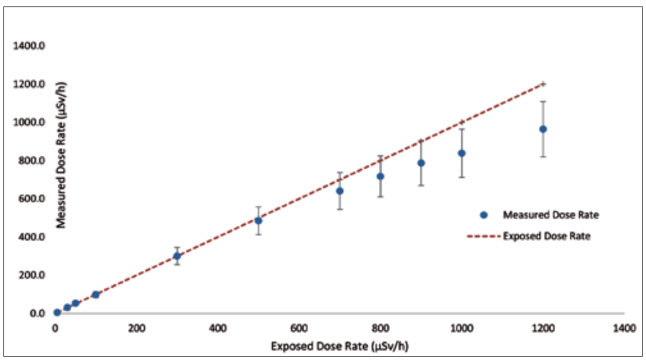


**Fig. 5.** Comparison between the measured dose rate and the exposed dose rate

calibration source were recorded. The bGeigie Nano Monitor was set in "bGeigie Mode"[5] and recorded the entire experiment. Therefore, not only did the monitor record the time taken for the GM to start measuring background dose rates once the $^{137}$Cs source[8] was taken away, but also the time taken for the dose rate to stabilise as well. During this test, the bGeigie Nano Monitor was in a fixed position. Therefore, this only tested the stabilisation time of the monitor in one fixed position.

### *2.7. Angular Response*

During the calibration of the bGeigie Nano Monitor an angular response test was performed to see how well the GM pancake responded. The test was performed in the EPA calibration facility. The pancake GM was aligned to the centre of the Hopewell irradiator using a laser pointer. As before in the calibration test a background reading was taken before the irradiation, during the irradiation six measurements were taken when the dose rate had stabilised, the exposed dose rate was the same for each angle. As this was the first angle (Straight on) this was taken as 0°. From here the bGeigie Nano Monitor was turned clockwise 45° and measurements were taken as previously stated. This step continued until the monitor had had tuned 360° and measurements had been taken for every 45° angle.

## 3. Results

### *3.1. Calibration Test of the bGeigie Nano Monitor*

Table 3 compares the exposure dose rate of the $^{137}$Cs calibration source and the corresponding reading by the bGeigie Nano Monitor. For this data, the measured dose rate of the monitor had the background dose rate of the calibration facility subtracted from the measured dose rate to give a better representation of the measured dose rate. The measured dose rate was rounded to 3 decimal places because the monitor can measure as accurately as up to 3 decimal places, and the uncertainty was taken as ±15%[5] as this is the accuracy specified by the specifications on the Safecast webpage[3]. Figure 5 shows the comparison between the measured dose rate by the bGeigie Nano Monitor and the exposure dose rate of the $^{137}$Cs calibration source[9]. The trend line indicates the expected dose rate measured.

### *3.2. Comparison of Monitors*

Figure 6 shows the comparison between the bGeigie Nano Monitor and the ENVINET[4]. The results themselves are averages over the space of 1 hour. The uncertainties on the measurements were taken as the manufacturers specified uncertainties for each monitor[3]. The Zeta test[10] result for the monitors in comparison with the bGeigie Nano Monitor was calculated to be 0.51 which would indicate good agreement. The uncertainties used were the manufacturers stated uncertainties[5].

### *3.3. Test of response of detector to different source types (Beta and Gamma)*

Table 4 shows the comparison between the measured dose rates of $^{90}$Sr/$^{90}$Y and $^{241}$Am when the case is on and off the bGeigie Nano Monitor. The results were taken when the monitor was in contact with the source. Due to

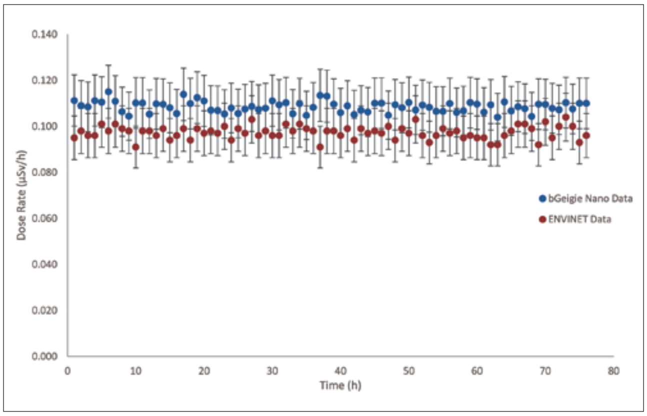


**Fig. 6.** Comparison dose rate measurements between the bGeigie Nano Monitor and the fixed gamma dose rate monitor[4] (ENVINET).

**Table 4.** The measured CPM of $^{90}Sr/^{90}Y$ and $^{241}Am$ with the case on and the case off the bGeigie Nano Monitor

| Case On | | Case Off | |
|---|---|---|---|
| $^{90}Sr/^{90}Y$ | Dose Rate (CPM) | $^{90}Sr/^{90}Y$ | Dose Rate (CPM) |
| | 48 | | 1438 |
| | 51 | | 1423 |
| | 45 | | 1409 |
| | 40 | | 1418 |
| | 36 | | 1412 |
| $^{241}Am$ | Dose Rate (CPM) | $^{241}Am$ | Dose Rate (CPM) |
| | 1215 | | 1915 |
| | 1223 | | 1924 |
| | 1232 | | 1940 |
| | 1236 | | 1947 |
| | 1222 | | 1943 |

the fluctuation in the readings five or more readings were taken to get a mean value.

*3.4. Stabilisation time of detector readings in response to variations in the radiation field*

Figure 7 shows the recorded dose rate of the EPA's calibration facility $^{137}Cs$ source[9] when it was set at an exposure rate of 50 μSv/h. This was recorded and measured using the bGeigie Nano Monitor in "bGeigie Mode"[3] which takes a reading every five seconds, hence every data point on Figure 7 represents a five second time interval. In this measurement, the bGeigie Nano Monitor began recording the dose rate before the $^{137}Cs$ source[9] was exposed to the monitor. It was then left exposed until the measurements stabilised. The source was then removed and the bGeigie Nano Monitor was allowed to return to the background dose rate of the calibration facility. For this measurement, it was considered stable when the measurements plateaued (e.g. at 50 μSv/h or background dose rates) and the uncertainty used was the 15% as specified by the manufacturer[5].

*3.5. Angular Response*

Figure 8 shows response of the bGeigie Nano Monitor pancake GM when exposed to a dose rate of 10 μSv/h rotated at a 45°, Table 5 then shows the percentage difference between the *measured* dose rate and the exposed dose rate and their respective angle.

## 4. Discussion and Conclusions

*4.1. Calibration Test of the bGeigie Nano Monitor*

The stated operating range of the bGeigie Nano Monitor is .000 – 1000 μSv/h[5]. The GM was tested over this range using the EPA's calibration facility[3]. The results show that the bGeigie Nano Monitor is in good agreement from 5 – 900 μSv/h, but at 1000 μSv/h the measured dose rate was within 16% of the exposed dose rate, which is 1% off the manufacturers specified uncertainty for this range. This can be seen in Table 3. The uncertainty is seen to increase once exposed to dose rates above 1000 μSv/h, this is seen in Table 3 where the measured dose rate for the 1200 μSv/h is within 20% of the exposed dose rate. This result is expected as the pancake GM is oversaturated by the dose of the $^{137}Cs$ source[9], but again this is reasonable as it was not stated by Safecast that it could measure accurately above 1000 μSv/h. The main concern is that when the bGeigie Nano Monitor is exposed to dose rates above its threshold there is no warning sign to alert the user. The results found in this are similar to those reported by Wagner *et al.* (2016)[11] "The system performs well in the expected range of use, although users should be warned of the plateau that starts about 10 mGy/h . Above this level, users could be unaware that they are in an immediately life-threatening field.", whose measurements also started to suffer from over saturation above 1000 μSv/h. Knowing this, it is believed there should be a warning given with the bGeigie Nano Monitor when it has reached its threshold be that on the display or written on the website as part of monitor's user guide.

*4.2. Comparison of Monitors*

The comparison between the bGeigie Nano Monitor and the EPA's ENVINET[4] showed a good agreement between the measured dose rates. Over the same time frame, it can be seen in Figure 6 that the two GMs are measuring the gamma dose rates of the area with little variation between the readings from the two monitors. This is also demonstrated with the Zeta test[5] between the two monitors which at a value of 0.51 is < 2, which would indicate a good agreement between the bGeigie Nano Monitor and the EVINET[4] measurements.

The results in this experiment are supported by

**Table 5.** The measured angular response of the bGeigie Nano Monitor

| Angle (°) | Exposed Dose Rate (μSv/h) | Measured Dose Rate (μSv/h) | Percentage difference (%) |
|---|---|---|---|
| 0 | 10 | 9.8 | -2.1 |
| 45 | 10 | 8.9 | -11.4 |
| 90 | 10 | 4.7 | -52.6 |
| 135 | 10 | 6.1 | -39.4 |
| 180 | 10 | 7.0 | -29.7 |
| 225 | 10 | 6.3 | -37.2 |
| 270 | 10 | 6.2 | -37.8 |
| 315 | 10 | 9.0 | -9.6 |

the findings Coletti *et al.* (2017)[12] who found that the Safecast monitoring data in Japan taken by the bGeigie Nano Monitors that they had used were in agreement with the measurements that were gathered by the U.S. Department of Energy (DOE) and the U.S. National Nuclear Security Administration (NNSA). Therefore, it is believed that the bGeigie Nano Monitor has proven to perform well and produce reliable results in normal background dose rate areas.

### *4.3. Test of response of detector to different source types (Beta, and Gamma)*

The test response of the bGeigie Nano monitor to beta and gamma sources of radiation showed that, with the case on, the monitor could detect the radioactivity in CPM from the $\alpha$ and $\gamma$ emitting $^{241}$Am source and the β emitting $^{90}$Sr/$^{90}$Y source. This can be seen in Table 4. The radioactivity detected for $^{241}$Am fits as expected, as it is an alpha and gamma emitter, meaning with the case on it was measuring the gamma radioactivity of the source. For $^{90}$Sr/$^{90}$Y, there was a small activity detected with the case on the monitor. This was because as $^{90}$Y (2.3 MeV) is a high energy beta emitter, the case may not have enough stopping power to completely attenuate the high energy beta particles from this radionuclide.

With the case off the bGeigie Nano Monitor, the results changed significantly. These can also be viewed in Table 4. For $^{90}$Sr/$^{90}$Y, the increase in detected radioactivity was very large. This indicates that, with the case off the monitor, there was little or no attenuation of the beta particles before being detected by the monitor. Therefore, without its case on, the bGeigie Nano Monitor can detect beta emissions more easily. Results have also shown that, with the case on the bGeigie Nano Monitor, it can detect high energy beta emissions from $^{90}$Y.

### *4.4. Stabilisation time of detector readings in response to variations in the radiation field*

During testing with the bGeigie Nano Monitor, it became apparent that when the GM pancake[8] was measuring high dose rates above background dose rate levels, it could take up to a minute for the dose rate being measured to stabilise. The results of this experiment can be seen in Figure 7 which shows the bGeigie Nano Monitor taking approximately one minute to plateau and stabilise at 50 μSv/h, and for it to take approximately one minute to return to background dose rates after the removal of the source. This shows that after contact with an ionising radiation source higher than normal background radiation levels, time should be taken for the bGeigie Nano Monitor to both measure ionising radiation source and return to background dose rate levels after the removal of the radiation source before taking measurements again for it to be accurate.

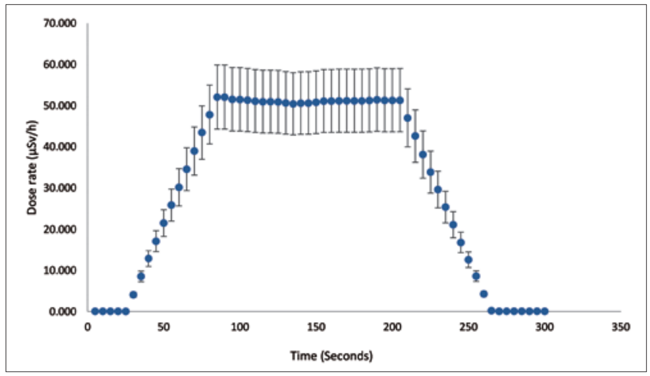


**Fig. 7.** The measured dose rate of the Hopewell $^{137}$Cs source[9] when it was set at 50 μSv/h.

The results found in this experiment also match those reported by Wagner *et al.* (2016)[11] “The system does display a time-weighted average of the count rate, so there is a significant issue of rapidly varying radiation fields, such as entering or exiting a building. For each measurement, the authors were forced to wait approximately 1 min for the reading to stabilize to a constant range.” who also found that during their measurements, they needed to wait up to one minute for their readings to stabilise to a constant range. They also noted that in their results, even after giving the monitor one minute to stabilise, there was still fluctuation on the measured dose rates. Therefore it is agreed with Wagner *et al.* (2016)[11] that the stabilisation times is

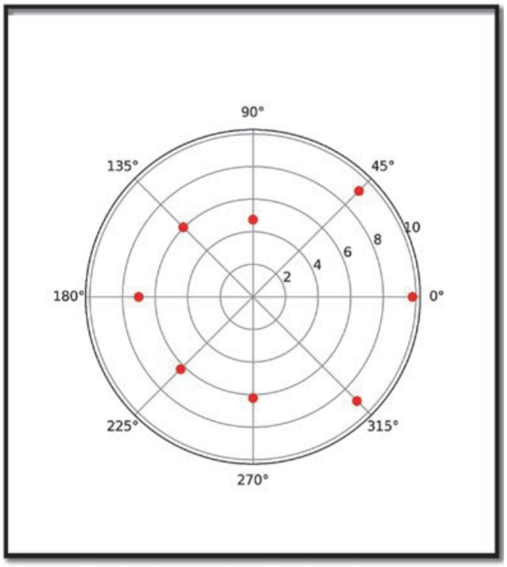


**Fig. 8.** Angular response of the bGeigie Nano Monitor.

effected by the weighted time average count rate, as the measurement is saved and updated every 5 seconds it is slower to react to a rapidly changing radiation field. It is believed that this should be mentioned and cautioned when in use.

### *4.5. Angular Response*

It can be seen in Figure 8 and Table 5 that the measured dose rate can vary quite dramatically depending on what way the bGeigie Nano Monitor is facing the radiation source. This is especially evident at 0° and 90°, at 0° the measured dose rate and exposed dose rate are within 4% respectively while at 90° the difference is 50%. This drop off shows the importance of indicating the way in which the bGeigie Nano Monitor was orientated when taking measurements and reporting results.

## Conflict of Interest Disclosure

All the authors report no conflicts of interest.

## References

1. Brown A, Franken P, Bonner S, Dolezal N, Moross J. Safecast: successful citizen-science for radiation measurement and communication after Fukushima. J Radiol Prot. 2016;36:82–102. doi:10.1088/0952-4746/36/2/s82.
2. Safecast.org [Internet] Safecast Tile Map. [cited 2018 Nov 25]. Available from: http://safecast.org/tilemap/
3. Iso.org [Internet] ISO/IEC 17025:2017. ISO/IEC 17025:2017 2018. [cited 2018 Nov 25] Available from: https://www.iso.org/standard/66912.html
4. Envinet.com [Internet] MIRA – Gamma Dose Rate Detection. Gamma Dose Rate MIRA - ENVINET GmbH. [cited 2018 Nov 25]. Available from: https://envinet.com/en/products/gamma-dose-rate-mira.html
5. Githhub.com [Internet] Safecast. Safecast/bGeigieNanoKit. GitHub. [cited 2018 Nov 25]. Available from: https://github.com/Safecast/bGeigieNanoKit/wiki
6. Kithub.cc [Internet] Safecast bGeigie Nano - Mobile Radiation Monitoring Device. KitHub. [cited 2018 Nov 25]. Available from: https://shop.kithub.cc/products/safecast-bgeigie-nano
7. Githhub.com [Internet] Safecast. Safecast/bGeigieNanoKit. GitHub. [cited 2018 Nov 25]. Available from: https://github.com/Safecast/bGeigieNanoKit/wiki/Assembly-Manual
8. LNDinc.com [Internet] 7317. LND | Nuclear Radiation Detectors. [cited 2018 Nov 25]. Available from: https://www.lndinc.com/products/geiger-mueller-tubes/7317/
9. Hopewelldesigns.com [Internet] Hopewell Designs Inc. gamma irradiators. [cited 2018 Nov 25]. Available from: http://www.hopewelldesigns.com/gamma_irradiators.html
10. NPL.co.uk [Internet] NPL Environmental Radioactivity Comparison 2007 : Products & Services : Radioactivity : Science Technology. National Physical Laboratory 2008. [cited 2018 Nov 25]. Available from: http://www.npl.co.uk/science-technology/radioactivity/products-and-services/npl-environmental-radioactivity-comparison-2007
11. Wagner E, Sorom R, Wiles L. Radiation Monitoring for the Masses. Health Phys. 2016;110:37–44. doi:10.1097/hp.0000000000000407.
12. Coletti M, Hultquist C, Kennedy WG, Cervone G. Validating Safecast data by comparisons to a U. S. Department of Energy Fukushima Prefecture aerial survey. J Environ Radioact. 2017;171:9–20. doi:10.1016/j.jenvrad.2017.01.005.