The reliability and validity of detecting low dose radiation when using radiation detection applications and devices for smartphones.

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Keywords

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Abstract

Introduction: Recent studies have stated that the use of real time dosimeters decreases occupational dose. Since 2015, 54.9% of the European population carries a smartphone and new technology gives us the opportunity to use smartphones as real time dosimeters. The aim of the study is to investigate the reliability and validity of using the smartphone with applications or peripherals as a personal real time dosimeter.

Method: Three different makes of Android smartphones were used with RadioactivityCounter, Pocket Geiger Type6 and Smart Geiger. Tests were done with x-ray radiation, and the devices were used to measure the dose rate from sources of the isotopes; ^{57}Co, ^{99m}Tc and ^{137}Cs.

Results: The short exposure time (x-ray pulse) showed measurement equal to the background radiation, however the constant exposure time showed some reliable and valid results. The Smart Geiger showed -71.51 ±7.1% average accuracy, the RadioactivityCounter showed -55.79% ±44.7% average accuracy while the Pocket Geiger Type6 showed a -25.52% ±10.8% average accuracy.

Discussion and conclusion: During the short exposure test, no radiation was detected. This is due to the software being designed for constant dose rates. When exposed to a constant radiation source; The Smart Geiger reported low doses, but there was no proof to suggest the device was actually detecting radiation; the RadioactivityCounter had a higher reliability and validity than the Smart Geiger; the results suggest that the Pocket Geiger Type6 could be possible reliable and valid detection device.

Introduction

According to the World Health Organisation there are 3.6 billion X-ray examinations performed, 37 million nuclear medicine procedures carried out and 7.5 million radiotherapy treatments delivered worldwide annually. Several of these scenarios involve a member of staff receiving a low dose of radiation

Recent studies suggest that using real time dosimeter in certain clinical settings reduces occupation dose.[2] Different technologies are available to demonstrate occupation dose measurement, for example, bespoke technology (e.g. TLD badges) or generic technology (e.g. Smartphones). Smartphones have the potential to be converted into personal real time dosimeters by the use of radiation detection applications and peripherals (interface devices), as they contain a complimentary metal-oxide-semiconductor (CMOS) sensor in the camera.[3] As of 2015, 54.9% of all the European population carry smartphones, with predictions for 2017 reaching over 65%.[4] This indicates a great potential for the smartphone as a dose monitor.

The criteria and performance limits of the personal dosimeters for ionising radiation are set in the ISO14146:2000 standard. It states that the personal dosimeter can have an accuracy with an error of anywhere between ± 50% of the true dose, and still be valid for use.[5]

Due to shortage of research into the potential clinical use of the applications and peripherals for smartphones, this research will provide information about the reliability and validity of the application "RadioactivityCounter",[6] the USB attachable "Pocket Geiger Type6",[7] and the audio jack attachable "Smart Geiger".[8] These will be compared to standard dose rate measurement equipment, the UNFORS Xi and a Messbereich FH40F2.

Should dose readings from smartphones be proven reliable and valid as the personal dosimeters used in hospitals today,[5] they would provide a readily available way to measure dose in real time. This has the potential to reduce occupation dose.

Materials and methods

Equipment

In this study two peripherals and one stand-alone application (collectively referred to as devices) for measuring radiation are discussed. All of which are available to the public as they are easily purchased from internet suppliers (Table 1). The devices were combined with three different smartphones from HTC, Samsung and Sony (Table 2). The different types of smartphones provide inter-rater reliability in this study.

The CMOS chip in the camera of the smartphones is a semiconductor, which converts photons into electrical charges. This is measured by the RadioactivityCounter,[6] as a count, which is then converted into a dose rate. The CMOS chip is sensitive to visible light,[9] therefore; two pieces of electrical insulating tape were placed over the lens

Table 1 The price and producer for the devices

Device	Price	Producer
RadioactivityCounter	€3,5	Rolf-Dieter Klein
Pocket Geiger Type6	€40	Radiation-Watch
Smart Geiger	€30	FT Lab

Table 2 The distributor, model and FCC ID for the smartphones

Manufacturer	Model	FCC ID
Samsung	Galaxy s4	A3LGTI9506
HTC	One M7	NM8PN07100
Sony	Z3 compact	PY7PM-0810

of the camera to reduce the chance of visible light being detected.[6] The CMOS chip would then only be exposed to ionising radiation able to penetrate the insulating tape.[6] The Pocket Geiger Type6 and the Smart Geiger have external semiconductors, and these are used to detect the radiation, instead of the camera CMOS chip.[7,8]

The data was collected separately in three experiments; therefore, the method will be divided in three parts; short exposure time, constant exposure with different sources and constant exposure with different distances

Short exposure time using X-Radiation
An x-ray unit (DIGITAL DIAGNOSTIC NZR 83, PHILIPS, Netherlands), with a 0.22 mmCu and a 1.0 mmAl filter was used to perform this experiment. A stack of Plexiglas measuring 16 cm in height and a width of 30 cm was used as a phantom to create realistic scattered radiation.

The phantom was positioned at the end of the x-ray table, correctly centred to the main radiation beam, with collimation of 18cm x 18cm. Tube voltage was set on 125 kVp and the tube load was set at 25 mAs. The devices were placed 30 cm away from the edge of the phantom, as illustrated in Figure 1.

Basic measurements with an UNFORS Xi dosimeter were done to ensure the secondary radiation was the same at different angles and heights, so that the position of the devices had no effect on the results.

Constant exposure with different radiation sources
To achieve a constant exposure time with different gamma energies and dose rates, three radioactive sources with different isotopes were used. The isotopes, activity and the calculated dose rates of the sources at 30 cm are listed in Table 3. Cobalt - 57 and Technetium - 99m emit photons with energy of 122keV and 141keV respectively and are often used in nuclear

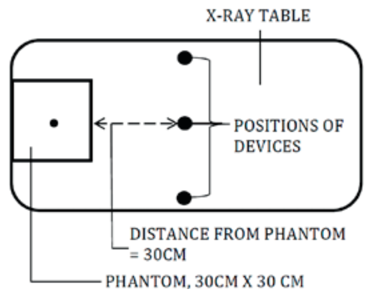

Figure 1 Setup of the short exposure time measurements

Table 3 The main energy, activity and calculated dose rate at 30 cm of the radioactive sources used.

	Main energy (keV)	Activity (μBq)	Calculated dose rate (μSv/h)
57Co	122	1.10	0.28
137Cs	662	6.74	6.96
99mTc	141	82.4	21.06

medicine.[10] Caesium - 137 (gamma energy 662keV) is used in medical therapy as a cancer treatment.[11]

The setup of the measurement is seen in Figure 2. All radioactive sources were individually placed at point O. The three devices were placed at each of the points A, B and C, all 30 cm from point O. The Messbereich FH40F2 was placed at D, also 30 cm from point O. The devices remained in the same spot for each measurement, but the placement of the smartphones were alternated to create the different combinations. The sensors were pointed towards the source, to ensure directional sensitivity did not affect the results.[13] The smartphones were set in flight mode, the Wi-Fi was turned off and the media volume was turned up to optimise the working conditions of the devices.

The level of radiation at each position was measured using a Messbereich FH40F2, to ensure the results could be compared. The FH40F2 was seen to give the true value, due to it being calibrated for hospital use. Each time the isotope was changed, points A, B, C and D were measured for 3 minutes using the FH40F2, to ensure all four points were receiving the same level of radiation.

The Pocket Geiger Type6 and the Smart Geiger showed an average dose rate after 5 minutes of continuous recording. The RadioactivityCounter logged a dose rate every minute and was left to record for 5 minutes and an average was taken. The results are shown in Table 5.

Constant exposure with different distances

To further test the abilities of the devices to measure different dose rates, another ^{137}Cs source (0.22MBq) was used and the devices were tested at three different distances; 15 cm, 30 cm and 45 cm from the source, see Figure 3.

The true dose rate was calculated for the low activity ^{137}Cs source, 0.912 μSv/h at 15 cm, 0.228μSv/h at 30 cm and 0.101μSv/h at 45 cm. Dose rate measurements of the nine combinations of devices and smartphones were recorded for 5 minutes at each of the three distances. The results are displayed as three graphs in Figure 4. The calculated

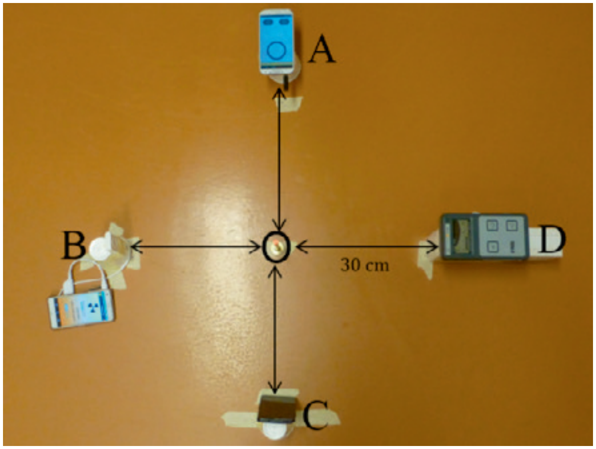

Figure 2 Setup of measurement with Constant exposure, different sources. The devices are A: Smart Geiger, B: Pocket Geiger Type6, C: RadioactivityCounter and D: Messbereich FH40F2. Aall devices were 30 cm from point O were the different radioactive sources were placed.

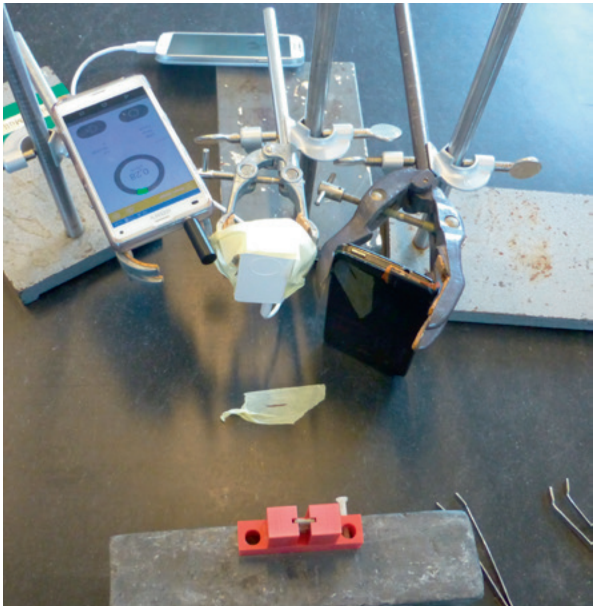

Figure 3 Setup of the measurement with constant exposure, different distances (15 cm, 30 cm and 45 cm) from the source, to get different dose rates with a ^{137}Cs source. The image shows the situation with 15 cm.

true dose rate is also shown in the graphs to provide a visual comparison.

Data analysis

The data were compiled into a table using Microsoft Excel 2010, displaying all values taken from the different combinations of the equipment. The accuracy from the different smartphone and devices was determined. And an equation was used to determine the validity of the results compared with the standard detection device or calculation, allowing the validity to be seen as % error:

$$\% \text{ error} = h \; - \; h \;\; h \; *100\%. \quad \text{Eq } 1$$

Where *h* is measured dose (μSv) per hour with one of the devices and *h* is the same unit from standard dose measurement equipment or calculated dose rate, seen as the true dose. If the % error is between ± 50%, the device will have the reliability needed to be used as a personal dosimeter.[5]

To assess the validity of each device the standard deviation of the % error was calculated, both for each smartphone used with one device and all measurements done with that device.

Results

Short exposure time

The measurements received when using the short exposure times all showed a peak at the point of exposure. However, these readings dropped to a background dose rate in a few seconds due to the short exposure. The background exposure measurements can be seen in Table 4. The UNFORSE Xi measured the short time exposure to give a dose between 5.3 and 9.2 μSv per exposure.

Table 4 Measurements of the background dose rate and counts per minutes(CPM) using the different brands of smartphones and all devices

Smart-phone	Radioactivity-Counter		Pocket Geiger Type6		Smart Geiger	
	Dose rate (μSv/h)	CPM	Dose rate (μSv/h)	CPM	Dose rate (μSv/h)	CPM
HTC	18.54	15.2	0.03	1.80	0.10	0.0
Samsung	0.06	1.8	0.06	3.20	0.10	0.0
Sony	0.08	9.0	0.07	3.80	0.10	0.0

Radiactivity-Counter	COBALT Dose rate 0.29 μSv/h			CAESIUM Dose rate 6.43 μSv/h			TECHNETIUM Dose rate 13.77 μSv/h		
	Average CPM	μSv/h	% error	Average CPM	μSv/h	% error	Average CPM	μSv/h	% error
HTC	13.6	0.07± 0.00	-75.86	7.0	0.06± 0.00	-99.07	29.4	10.52±10.48	-23.60
Samsung	2.3	0.13± 0.12	-55.17	4.2	0.68± 0.55	-89.42	44.8	17.72±2.95	28.69
Sony	11.6	0.07± 0.00	-75.86	43.2	21.32± 17.05	231.57	613.0	413.88±293.14	2905.66
Pocket Geiger Type6	**Average CPM**	**μSv/h**	**% error**	**Average CPM**	**μSv/h**	**% error**	**Average CPM**	**μSv/h**	**% error**
HTC	14.8	0.28± 0.03	-3.45	229.4	4.33± 0.13	-32.66	565.6	10.67± 0.20	-22.51
Samsung	9.6	0.18± 0.03	-37.93	225.6	4.25± 0.13	-33.90	536.0	10.11± 0.20	-26.58
Sony	12.8	0.24± 0.03	-17.24	225.0	4.24± 0.13	-34.06	574.2	10.83± 0.20	-21.35
Smart Geiger	**Average CPM**	**μSv/h**	**% error**	**Average CPM**	**μSv/h**	**% error**	**Average CPM**	**μSv/h**	**% error**
HTC	0.4	0.10	-65.52	11.6	1.82	-71.70	16.4	2.57	-81.34
Samsung	0.0	0.10	-65.52	13.2	2.07	-67.07	14.0	2.20	-84.02
Sony	0.0	0.10	-65.52	12.0	1.88	-70.76	11.8	1.85	-86.57

Table 5: Measured counts per minute. dose rate (μSv/h) and calculated % error of the devices for each smartphone and radioactive source. The dose rate of each source measured with the Messbereich FH40F2 is seen as the true dose rate when Eq. 1 is used.

Table 6 The standard deviation of the % error given in Table 5 of each of the devices both for each smartphone used with one device and all measurements done with that device

Device	Smartphone			Total
	HTC	Samsung	Sony	
RadioactivityCounter	±38.7 %	±60.8 %	±1640 %	±981 %
Pocket Geiger Type 6	±14.8 %	±5.8 %	±8.8 %	±10.8 %
Smart Geiger	±8.0 %	±10.1 %	±11.0 %	±8.5 %

Constant exposure with different sources

The results gathered when using a constant exposure with different sources are listed in Table 5. The average error and variation expressed as standard deviation are listed in Table 6. This variation will give an indication on the reliability of the measurements done with a device.

All devices were able to detect the increase in dose rate with different isotopes on all smartphones. However, the results from the RadiactivityCounter vary widely between -99.07% and +2905.66%. Two measurements with the Sony smartphone are obvious anomalies, ^{137}Cs and ^{99m}Tc, and just two of the nine measurements (^{99m}Tc with HTC and Samsung) are between ± 50% of the true dose. Due to the anomalies, the standard deviations seen in Table 6 are very large for the RadiactivityCounter when using the Sony smartphone, ±1640 %. Also the measurements with HTC and Samsung have a substantial variation with standard deviations, 38.7 % and 60.8 % respectively.

As seen in Table 5, the Pocket Geiger Type6 is able to follow the increase in dose rate as stronger radioactivity sources are applied. The accuracy ranges from -3.45% to -39.93%. In Table 6 the variation of the measurement with this device have a standard deviation of total ±10.8%, in the case of the Pocket Geiger Type6 it is the HTC which has the largest variation with a standard deviation of ±14.8%.

Table 6 also shows that the Smart Geiger has the lowest variation in error between the nine measurements done with this device. It can be noted that the Smart Geiger will not give dose rate values below 0.1 μSv/h. It will give this value as an estimate of the background radiation. When measuring the lowest dose rate from the ^{57}Co all of the measurements are equal this "background" dose rate. When looking at the reliability all the nine % error calculated from Eq. 1 are negative and larger than the ± 50% error.

Constant exposure with different distances

When testing the devices' ability to detect change in dose rate due to change in distance, the RadioactivityCounter did not follow the expected pattern (Figure 4a). The Samsung smartphone did initially show a decrease in dose rate when the distance was increased from 15 to 30 cm. But when the distance was 45 cm it was followed by an unexpected increase. The HTC smartphone maintained an almost constant dose rate regardless of distance from the source, and the Sony smartphone showed an increase in dose rate as the distance increased.

As seen in Figure 4b the Pocket Geiger Type6 did follow the expected decrease in dose rate as the distance was increased. All three brands of smartphones followed a same declining pattern.

The Smart Geiger followed the expected pattern of dose rate declining as distance increased, shown in figure 4c. All three devices stopped at 0.10μSv/h at the 45 cm distance, the lowest dose value reported on this device. The device behaved in this way when attached to all three smartphones. However, the different phones have different dose rate response and the Sony with the reached the 0.10μSv/h at 30 cm.

Discussion

The results of the experimental study show that there is the potential to use smartphones to detect radiation in a clinical setting.

Short exposure time

The short exposure results proved that the devices are unable to detect short time exposure. This is not unexpected as all are dose rate meters designed to measure a constant exposure.6-8 The equivalent dose (μSv) from one short exposure would be averaged over the 5 minutes or in the case of the RadioactivityCounter 1 minute. The UNFORSE Xi measured the short time exposure to give a dose between 5.3 and 9.2 μSv. If a 5 μSv short time exposure was detected by the device in a 5 minute period, the dose rate per hour would be 12 times this, 60 μSv/h. All the devices possibly have an algorithm that categorize the short exposure as noise, thus not taking the short exposure into account when calculating the dose rate. If the software is adapted to measure dose and not in dose rate, it could possibly be used to detect short time exposures from x-ray imaging exposure. But it could also be that the dose rate is too large to be measured with the devices. Regardless as the devices are constructed the reliability or validity are very low when used in short time exposure situations.

The Smart Geiger

The Smart Geiger does not seem to have reliability or validity to be seen as a potential personal dosimeter. The measurements performed with the device all have a low dose rate reading or a measurement equal to the background estimate of 0.1 μSv/h. Failing to measure below 0.1 μSv/h reduces the reliability and validity for this device. It can also be added that during the experiment, the Smart Geiger also showed a high sensitivity to external signals -especially cell phone signals. Due to time constraints, this could not be investigated further.

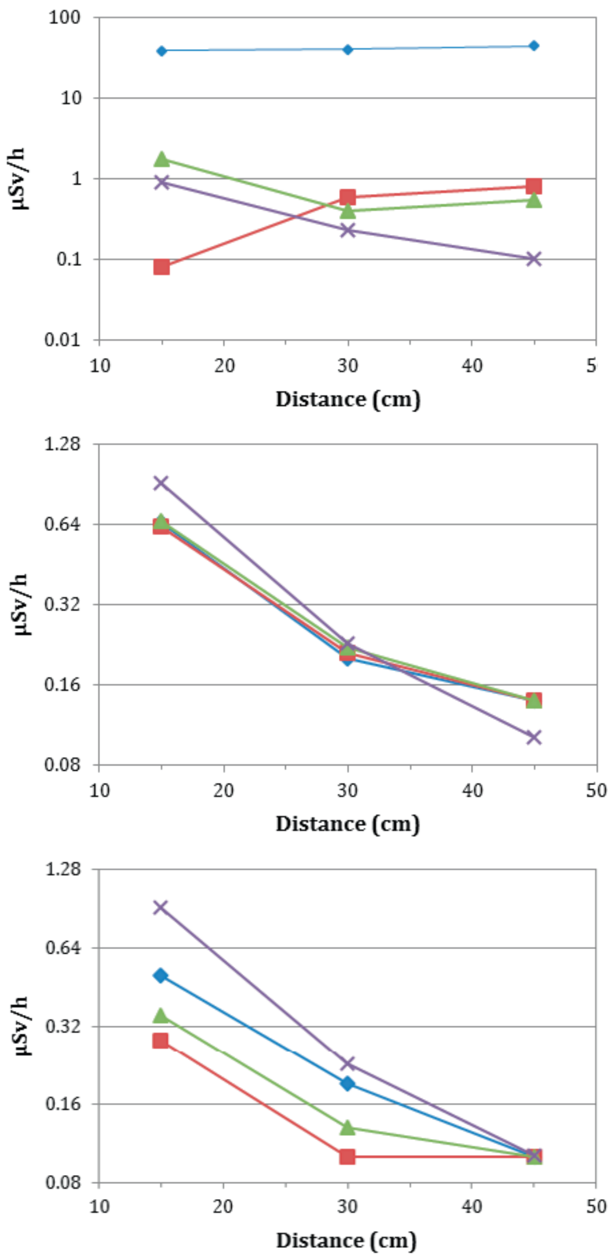

Figure 4 How the dose rate, detected by,
a) the RadioacticityCounter,
b) Pocket Geiger Type6 and
c) Smart Geiger changes with distance, all with use of the three smartphones HTC(blue), Samsung(green), Sony(red) and the calculated dose rate(purple).

The RadioactivityCounter

The RadioactivityCounter showed a higher reliability and validity to detect low dose rate radiation compared to the Smart Geiger. The counts per minute detected were dependent upon the hardware of the smartphone. To take the different smartphone hardware into account, the translation dose rate data found on the RadioactivityCounter website was used to calibrate all smartphones prior to use. Due to the lack data for the Sony Z3 Compact, an average of listed Sony smartphones was used. This potentially caused the high deviation the smartphones results. The HTC One gave the best reliability and validity of all the smartphones tested, even though it was stated on the RadioactivityCounter website that it should not be used.[6]

Tests regarding the influence of distance showed an increased in dose rate along with the distance from the radiation source. This unexpected result is not in accordance with inverse square law. A possible explanation for this is due to natural light from windows without curtains in the laboratory. When the experiment started at 15 cm, the sky was cloudy, but as the distance increased the sun broke through the clouds and the level of natural light in the laboratory increased. The RadioactivityCounter uses the built in camera of the smartphones and the camera have to be covered with black tape to prevent the light to expose the camera. The result seen in Figure 4a could be a result of the double layer of tape was too some degree transparent to light. Thus in a situation with variable light the covering of the lens should be infallible.

The Pocket Geiger Type6

The Pocket Geiger Type6 was shown to be the most reliable and valid device for measuring low dose rates. The best results were received when a Caesium isotope was used, which could be expected, as the original design was calibrated with Caesium.[7]

All measurements from combinations of radioactive sources and smartphones with this device are within ± 50% error, but all of them are too low.

Due to time constraints this experiment did not investigate possible directional sensitivity into account. As pointed out by Cogliati et al.[9] and Kaandorp and de Lange[12] this could interfere with the reliability and validity.

Conclusion

From our results it seems as the Pocket Geiger Type6 can be used as a reliable and valid detection device. A continual exposure situation with dose rates between 0.1-14μSv/h is an important margin. This device had an average error reading -25.52%, while a personal dosimeter may have an accuracy of anywhere between ± 50% of the true dose, and still be valid for use.[5]

It is interesting to see if this research could be followed up with an investigation into the use of the Pocket Geiger type6 during fluoroscopy.

Another approach is an investigation into the possibility to modify the software from the Pocket Geiger type6 to measure short exposures.

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References

1. World Health Organization. Medical radiation exposure [Internet]. World Health Organization; 2015 [cited 2015 Aug 26]. Available from: *http://www.who.int/ionizing_radiation/about/med_exposure/en/index3.html*
2. Müller MC, Welle K, Strauss A, Naehle PC, Pennekamp PH, Weber O, et al. Real-time dosimetry reduces radiation exposure of orthopaedic surgeons. Orthop Traumatol Surg Res [Internet]. 2014 Dec [cited 2015 Aug 26];100(8):947–51. Available from: *http://www.ncbi.nlm.nih.gov/pubmed/25459455*
3. Van Hoey O, Salavrakos A, Marques A, Nagao A, Willems R, Vanhavere F, et al. Radiation Dosimetry Properties Of Smartphone CMOS Sensors. Radiat Prot Dosimetry [Internet]. 2015 Jun 3 [cited 2015 Aug 26];ncv352 – . Available from: *http://rpd.oxfordjournals.org/content/early/2015/06/02/rpd.ncv352*
4. statista. Smartphone user penetration Western Europe 2011-2018 [Internet]. 2015 [cited 2015 Aug 26]. Available from: *http://www.statista.com/statistics/203722/smartphone-penetration-per-capita-in-western-europe-since-2000/*
5. ISO 2000. Radiation protection: criteria and performance limits for the periodic evaluation of processors of personal dosemeters for X and gamma radiation. Int Organ Stand [Internet]. 2000; Available from: *http://www.iso.org/iso/catalogue_detail.htm?csnumber=20876*
6. Klein R-D. RadioActivity [Internet]. MultiMediaStudio. 2014. Available from: *http://www.hotray-info.de/html/radioactivity.html*
7. Radiation Watch UK. Introducing the Radiation Watch Pocket Geiger Counter [Internet]. Radiation Watch UK. 2013 [cited 2015 Aug 25]. Available from: *http://www.radiation-watch.co.uk/*
8. FTLab. Miniature Radiation Sensor of national popular type [Internet]. FTLab. 2015 [cited 2015 Aug 25]. Available from: *http://allsmartlab.com/eng/Smart_Geiger.php*
9. Cogliati JJ, Derr KW, Wharton J. Using CMOS Sensors in a Cellphone for Gamma Detection and Classification. arXiv:14010766 [physics.ins-det] [Internet]. 2014;1–26. Available from: *http://arxiv.org/pdf/1401.0766v1.pdf*
10. World Nuclear Association. Radioisotopes in Medicine [Internet]. 2015 [cited 2015 Aug 25]. Available from: *http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Radioisotopes/Radioisotopes-in-Medicine/*
11. US EPA OORPD. Cesium [Internet]. 2000 [cited 2015 Aug 26]. Available from: *http://www.epa.gov/radiation/radionuclides/cesium.html*
12. Kaandorp J, de Lange R. Onderzoek naar de betrouwbaarheid van het meten van radioactiviteit binnen de Nucleaire Geneeskunde met behulp van smartphones. MIRT Hanze University of Applied Sciences; 2015.