Assessment of dose conversion coefficients for accident dosimetry with mobile phone components

Demi Römkens (BSc)
Fontys University of Applied Sciences | Engineering Physics
Belgian Nuclear Research Centre (SCK-CEN) | Radiation Protection Dosimetry & Calibration
demiromkens@hotmail.com

ABSTRACT

The resistors on the circuit board of a mobile phone can be used for accident dosimetry, because they exhibit optically stimulated luminescence due to radiation. The reconstructed dose from the resistors needs to be converted to organ absorbed doses. For this, Monte Carlo simulations are made. The resulting theoretical conversion coefficients are experimentally validated within this research. The main conclusion of this research is that the theoretical conversion coefficients do not significantly differ from the experimental conversion coefficients. However, during the dose reconstruction, various factors, such as fading and photon energy dependence can influence the reconstructed dose and introduce inaccuracies.

Keywords
Accident dosimetry, optically stimulated luminescence, mobile phone components, radiological protection, conversion coefficients.

INTRODUCTION

In case of a radiological accident or a terrorist attack with a dirty bomb, members of the public could be exposed to significant doses of ionizing radiation. In that case, it is very important that exposed and non-exposed persons can be separated as soon as possible and that the received dose can be estimated to start up proper medical treatment, if necessary. For this, one can rely on different personal objects with materials that exhibit radiation induced optically stimulated luminescence (OSL). After exposure to ionizing radiation, such materials emit visible light upon heating or illumination. Previous research has shown that mobile phone resistors have good dosimetry properties. By performing stimulated luminescence measurements on the mobile phone resistors, one can deduce to which dose these components were exposed. [3]
However, one is actually interested in the dose deposited in the different organs of the victim. Therefore, it is also important to know how to convert from the doses in the mobile phone resistors to organ absorbed doses. These conversion coefficients are currently calculated theoretically with Monte Carlo radiation transport simulations (MCNP). However, these calculations are not validated experimentally yet.

The research question is as follows:
Are the experimentally determined conversion coefficients and the theoretically calculated conversion coefficients significantly different from each other?

Previous research already showed the various factors that could influence the reconstruction of the original accident dose; the dose response, the fading of the signal and the photon energy dependence. [3] However, the possible introduced inaccuracies by the factors are not specifically described and investigated as is done in this research.

METHODOLOGY

Within this research, mobile phone resistors with a length and width of 1.0x0.5 mm are used. The resistors can be irradiated at the SCK-CEN secondary standard dosimetry laboratory with gamma (^{60}Co and ^{137}Cs) sources and X-rays. The optical stimulation luminescence (OSL) measurements are performed with the TL/OSL Riso reader which is also equipped with a $^{90}Sr/^{90}Y$ beta source. The resistors are extracted from the mobile phone in a dark room with red light. Figure 1 shows the resistors on the circuit board and in a sample cup. Each cup typically needs to contain 10 resistors for a sufficient OSL signal.

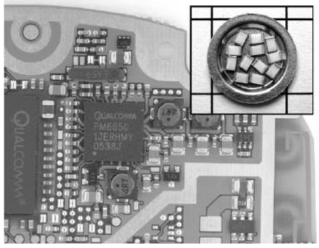

Figure 1: Resistors on the circuit board and in a sample cup. [7]

First, the various causes of uncertainty during the dose reconstruction from the mobile phone components are investigated.
In order to check the linearity of the dose response and its possible introduced uncertainty, the resistors are first irradiated with an accident dose that was varied between 0 Gy and 10 Gy and read-out with the TL/OSL Riso reader immediately. The reconstructed dose is then compared to the original given accident dose. The given accident dose is always expressed in terms of Air Kerma.

The time between irradiation and the measurements results in fading of the signal. This fading is characterized in order to reconstruct the original absorbed dose in the resistors. The fading is dependent on the time between irradiation and measurement, but also on the usage of preheat or not. The preheat of the samples results in stimulating the shallow electron traps. When using preheating, fading will occur with a slower rate because the electrons are only captured in the stable deep electron traps. The fading functions have experimentally been determined by the German Research Centre for Environmental Health, these functions are considered as the universal characterization for the fading effect. These fading functions are experimentally validated for this specific research by irradiating the resistors with 5.38 Gy with the beta source and performing the read-out after 0, 1, 2, 4, 6, 9, 12 and 15 days. This validation is also done to obtain an intercomparison between the research centres. The fading function describes the fading factor, this is the factor of the original given accident dose that can still be reconstructed from the resistors.

The reconstructed accident dose can be dependent on the energy of the photons or electrons of the radiation. Because the OSL signal from the irradiated resistors always needs to be quantified with the beta source within the Riso reader;

The resistors are irradiated again after the first read out with a known dose, in order to quantify the first outcome of the OSL measurements. However, this beta source emits an energy spectrum of electrons with a maximum of 2.27 MeV. To check for the influence of irradiation with photons with a lower energy, the resistors are irradiated with a known dose of ±5 Gy (at 0.75 m) from the gamma sources and X-rays, which contain lower photon energies. The reconstructed dose can be compared the original accident dose.

The dose conversion coefficient is the ratio between the organ absorbed dose and the mobile phone resistor dose. These coefficients can be experimentally determined by using an anthropomorphic phantom, the Rando Alderson phantom in this research. Within this phantom, the organ absorbed dose of the red bone marrow (RBM), the lungs and the stomach are determined with thermoluminescent LiF detectors. [5]
Mobile phones of the type of the NOKIA Lumia 820 are placed at four positions at the body of the phantom; the chest, the left buttock, the left upper leg and the left hip. The phantom is placed at 1.50 m from the ^{137}Cs source. By this, the set-up in the already made MCNP simulation is experimentally approached. The simulation contains the ICRP Voxel male phantom and is irradiated with a point source. The theoretically calculated conversion coefficients are compared to the experimentally obtained conversion coefficients. [2][4]

RESULTS

Dose response

Figure 2 shows the reconstructed dose on the vertical axis (De) and the original given dose on the horizontal axis (Da). The results show that the reconstructed dose increases proportionally with the original given accident dose. Also, the reconstructed dose matches the original given dose within their error ranges. This error range is based on the standard deviation between the samples containing the resistors and the error in the dose rate of the beta source. The dose response does not introduce any necessary corrections or additional inaccuracies.

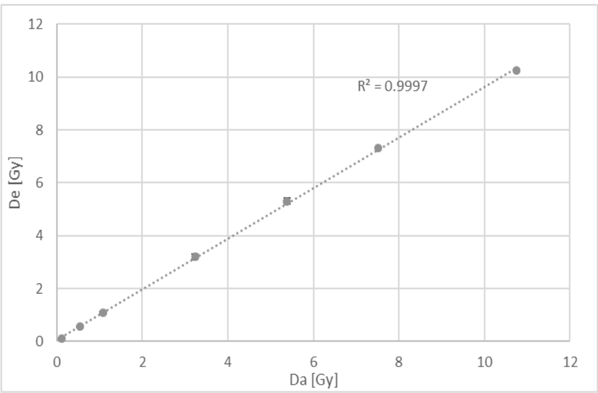

Figure 2: The dose response.

Fading

The universal fading function is determined by the German Research Centre for Environmental Health for both cases of preheating and no preheating. The universal fading function, without preheating, is expressed with equation 1.

$$F = \frac{t_{acc}}{t_{cal}}^{-0.22 \pm 0.04} \qquad [1]$$

Where, F is the fading factor, t_{acc} is the time between irradiation and the reconstruction and t_{cal} is the time between the measurement and the quantification within the Riso reader. Figure 3 shows the experimentally determined and universal fading function with no preheating. The experimental fading curve does not match the universal fading curve within its error ranges. The experimental fading curve can be fitted with equation 2.

$$F = \frac{t_{acc}}{t_{cal}}^{-0.146 \pm 0.009} \qquad [2]$$

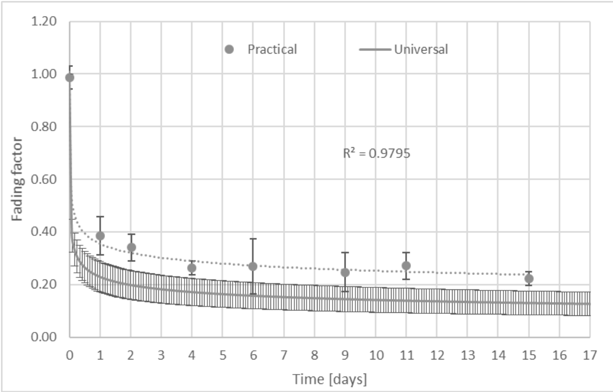

Figure 3: The fading functions when no preheating is used.

The difference between the two functions can be found in the measurement settings. The universal function is determined at room temperature, in this research a read temperature of 100°C is used. This comparison shows that it is important to use the same read-out protocols within each research centre.

The same experiment is done for fading in the case of preheat at 120 °C with a rate of 2 °C/s. Equation 3 shows the universal fading function.

$$F = \frac{1 - 0.11(\pm 0.03)\ln(t_{acc})}{1 - 0.11(\pm 0.03)\ln(t_{cal})} \qquad [3]$$

Figure 4 shows the universal fading function and the experimental obtained fading function with using preheating.

In this case, the experimental fading curve does match the universal fading curve. It is stated that the universal function is valid. The fading function of equation 3 can be used to correct the reconstructed dose in order to obtain the original absorbed dose.

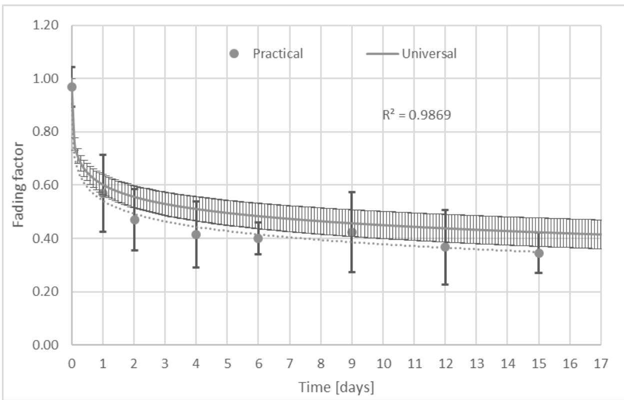

Figure 4: The fading functions when preheat are used.

In Figure 5, where the corrected reconstructed dose is normalized to the original accident dose for each delay time (t_{acc}), it can be seen that these match with each other within their error ranges.

However, when these error ranges are not taken into account, the reconstructed dose can be underestimated up to 20%. This inaccuracy needs to be taken into account and is based on the error in the reconstructed dose itself and on the error function of the fading function, provided by the German Research Centre for Environmental Health.

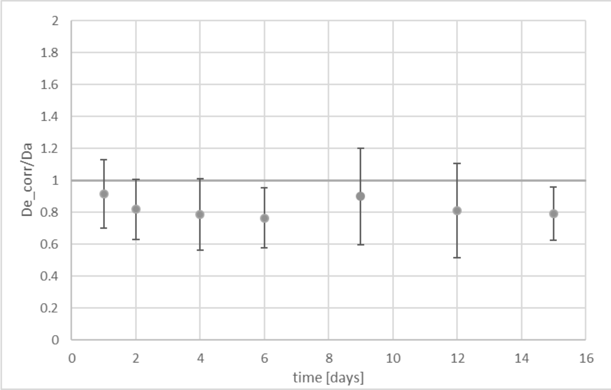

Figure 5: The corrected dose compared to the accident dose, when using preheating.

Photon energy dependence

To check the photon energy dependence, ten samples with each ten mobile phone resistor are irradiated with ^{137}Cs (662 keV), $^{90}Sr/^{90}Y$ (2.27 MeV), ^{60}Co (1.25 MeV) and an X-ray generator (poly-energetic photons with a mean value of 100 keV). Figure 6 shows the reconstructed dose normalized to the given accident dose for the different photon energies.
The results indicate that the absorbed dose in the resistors increases with decreasing of the photon energy, but the original given accident dose is ±5 Gy for all irradiations. The dose increases with a power function as function of the photon energy. At low energies, the dose can be overestimated up to 60%. The overestimation can be explained with the energy absorption coefficient for Al_2O_3, normalized to the energy absorption coefficient for air. This ratio increases with a power function with lower photon energies. With the same amount of Air Kerma, more photons are absorbed by the resistors and thus more electrons are excited to the conduction band. This will result in a higher OSL signal. [1]
This causes an overestimation when the reconstructed dose from the resistors is quantified with the energy absorption of the beta source within the Riso reader.
However, in order to determine a correction function and the corresponding error function, more data points are necessary. But, even when a power function and its introducing inaccuracy is available, the photon energy that is absorbed in the resistors needs to be known. In reality, this will be difficult due to the attenuation and scattering of the photons within the mobile phone or with its surrounding.

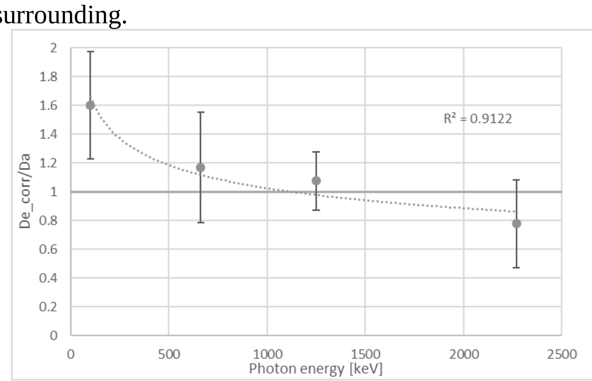

Figure 6: The source dependence on the ratio between the fading corrected retrieved dose and the accident dose.

Dose conversion coefficients

The dose conversion coefficients for converting from the four mobile phone positions to the three organs are determined. The dose conversion coefficient is the ratio between the mobile phone dose and the organ absorbed dose and is thus unitless. Figure 7 shows the experimental and theoretical conversion coefficients that can be used to convert from a mobile phone at various positions to the stomach.

The results show that the theoretically conversion coefficients match the experimentally obtained conversion coefficients. For the RBM and the lungs, the conversion coefficients also match.

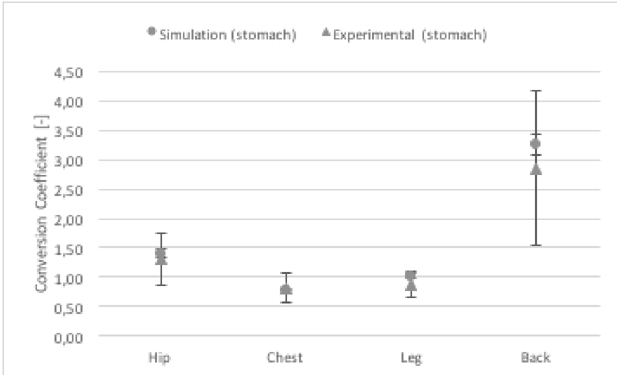

Figure 7: The theoretical and experimental conversion coefficients for the stomach.

DISCUSSION

The assessment of the dose conversion coefficients is done within an experiment with only one gamma source, one exposure geometry, one type of mobile phone and for only three organs. The considered theoretical conversion coefficients and the experimentally determined conversion coefficients do not differ significantly from each other.

However, results also showed that the theoretical organ or mobile phone absorbed dose itself cannot be compared with experimental results. Within the MCNP simulation, only the absorbed dose/fluence is available as a physical quantity. The fluence is the number of radiation particles through an infinitesimal sphere at a certain position per perpendicular area of the sphere. [6]
The usage of the fluence is not valid in this set-up. For the experiment, as well as for the simulation, the fluence needs to be determined at a reference point and the fluence needs to be assumed to be equal over the whole body. It is assumed that the fluence is equal for the whole phantom and the mobile phones. However, this is only valid for a perpendicular beam. With the use of the point source in this set-up, the beam is divergent. For example, the fluence at the leg of the phantom is 12% less than at the chest of the phantom, due to the inverse quadratic relation between the radiation intensity and the distance. However, only point sources are available and thus perpendicular beams are complicated to achieve.
There are also limitations to the approach that is considered in this research, within the simulation as well as in the experiments. The simulation and the experiment account for one type of person; a male of a certain weight and physique. In reality, the population consists of males, females, pregnant females and children with different physiques.
The error in the theoretical conversion coefficients is relatively low because it is only based on the statistics of the Monte Carlo calculations.

However, in reality this error will be much higher because of the spread between the conversion coefficients for all kinds of people.
Also, in the case of a nuclear accident, citizens will not be exposed to a point source. Exposure will more likely be caused by a radioactive cloud or by contamination of the ground surface. Within the simulation, this is already possible to simulate and conversion coefficients are determined for these situations. However, it is difficult to validate these corresponding conversion coefficients. Because, within an experimental set-up it is difficult to imitate a radioactive cloud or a contaminated ground surface.

CONCLUSION

This research showed the possibilities of using mobile phone resistors for accident dosimetry. During the dose reconstruction, various sources could introduce inaccuracies the reconstructed dose. The time between irradiation and dose reconstruction causes the signal to fade. However, correction functions are made for this and validated. Also, error functions need to be applied to obtain a reliable error range for the reconstructed doses.
The OSL signal obtained from the irradiated mobile phone resistors is always quantified with the beta source that is equipped within the Riso reader. But, the Al_2O_3 absorbs more photons at lower energies and thus more electrons are excited to the conduction band at lower energies than at the energy spectrum of the beta source. When the accident radiation contains lower energy photons, the dose could be overestimated up to 60%. However, it is complicated to correct for this because the absorbed photon energies due to an accident are not known.

With this research, it is concluded that the simulation is accurate enough to simulate exposures to citizens in different situations. The theoretically and experimentally determined conversion coefficients do not significantly differ from each other. This is a great advantage, as the possibilities to imitate different practical situations is much easier with the simulation than with the experimental set-up.
The error range introduced by the conversion coefficients is now relatively small, which indicates an extremely accurate reconstruction of the organ dose and this is not realistic. The inaccuracy that is introduced by converting the mobile phone dose to the organ absorbed dose is not known yet. The simulation can be used to determine the spread between the conversion coefficients for different kinds of people and exposure situations. This could yield a more accurate error range for the conversion coefficients. With these recommendations, the reconstruction of the organ absorbed dose and its corresponding error with the theoretical conversion coefficients can be done as accurate as possible.

ROLE OF THE STUDENT

This research is performed by Demi Römkens at the Belgian Nuclear Research Centre (SCK-CEN) under the supervision of dr. Olivier van Hoey. SCK-CEN is one of the largest research centres in Belgium. SCK-CEN works on the development of peaceful applications of ionising radiation. Issues that are important to society are investigated, such as radiation protection and calibration, the usage of nuclear installations and the disposal of radioactive waste.
With this research, a Bachelor of Science for the study Engineering Physics is obtained at Fontys University of Applied Sciences. This internship taught me to work independently as an engineer and enhanced my knowledge about solid state and nuclear physics. The work environment of SCK-CEN was pleasant, the broad diversity in work fields and nationalities showed the possibilities after graduation for working as well as for proceeding with studying.

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