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DEVELOPMENT OF A RETROSPECTIVE/FORTUITOUS ACCIDENT DOSIMETRY SERVICE BASED ON OSL OF MOBILE PHONES

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Work is presented on the development of a retrospective/fortuitous accident dosimetry service using optically stimulated luminescence of resistors found in mobile phones to determine the doses of radiation to members of the public following a radiological accident or terrorist incident. The system is described and discussed in terms of its likely accuracy in a real incident.

INTRODUCTION

Following a nuclear or radiological incident, large numbers of people could be exposed to significant doses of penetrating radiation. To determine who requires medical treatment, and to prioritise them, it is necessary to quickly estimate the doses that individuals received. Initially, this would involve dose categorisation rather than a precise dose determination, i.e. distinguishing those individuals who received a high dose (>1 Gy(1)) from those who did not.

This can be achieved using optically stimulated luminescence (OSL) of objects carried by people(2–4), e.g. chips from smart cards or electronic components such as resistors/capacitors/inductors in mobile phones. Resistors in mobile phones are considered to be the most promising candidate(5) with the widespread use of mobile phones making them a near ubiquitous retrospective/fortuitous dosemeter: the dose response for resistors has been found to be linear in the range 0.01–90 Gy(4), but the OSL signal fades(4–8) and the OSL response varies with photon energy(7, 8). This paper describes research performed to develop a retrospective dosimetry service that uses resistors from phones.

EXPERIMENTAL DETAILS AND METHODS

Irradiated and unirradiated mobile phones have been used in these studies. They are disassembled under red light, the circuit boards removed and resistors extracted. The resistors are of type *SMD 0402* (1 mm × 0.5 mm × 0.35 mm), the most common currently used in mobile phones, although there are trends towards smaller resistors. Sets of resistors are put on cups, sprayed with silicone oil to help hold them in place, with their white ceramic substrates uppermost.

OSL measurements are carried out with an automated luminescence reader(9) (Risø model TL/OSL DA-20) using blue LEDs (470 nm) as the stimulation light source delivering $\sim$80 mW cm^{-2} at the sample position. A photomultiplier tube (PMT) covered with a 7.5-mm U-340 Hoya filter (290–370 nm) is used for detection of the OSL. Samples are read out either at room temperature or using a heating protocol, for a stimulation time of a few to several tens of seconds. The heating protocol uses a pre-heat of 10 s at 120°C followed by OSL readout at 100°C(10). The 'net OSL signal', i.e. 'OSL signal' minus 'OSL background', is used in dose reconstruction calculations. The total PMT count is summed over the first 6 s of stimulation to give the OSL signal, and over 6–12 s to give the OSL background(10). The reader contains a 1.48 GBq ^{90}Sr/^{90}Y beta-particle source with a dose rate of 0.099 ± 0.004 Gy s^{-1} to irradiate samples.

Reconstruction of an unknown dose received by a cup of resistors requires the administration of a calibration dose using the reader beta-particle source. The accident dose can then be calculated using the net OSL signal, with a correction made for fading.

MEASUREMENTS AND RESULTS

OSL signal variation for different phones

It would not be anticipated that an unexposed phone would have zero signal. There are several sources of potential exposure, including natural background radiation, intrinsic activity in the alumina substrate and the phone being subjected to X radiography during manufacture. The first two of these may be expected to increase in severity with the age of the phone if there is a stable component to the signal, whilst the last should diminish with age. However, if the magnitude of this signal is large, it will impact on the accuracy of the assessment of the accident dose.

To investigate this, up to 10 sets of 10 resistors were extracted from 11 different phones; the number varied because not all phones contain the same number of usable resistors. These measurements required two

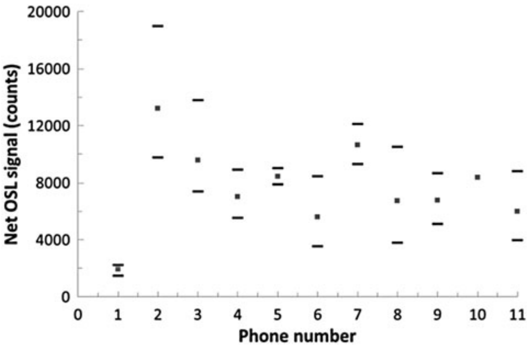

Figure 1. Net OSL signal for a dose of 0.8 Gy. All phones had at least 5 cups of 10 resistors taken except phone 10, for which only 1 cup of resistors could be removed.

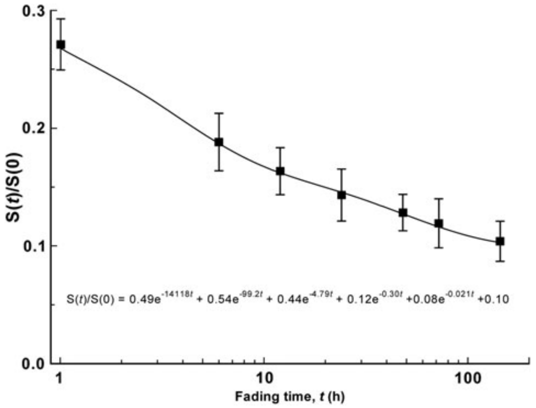

Figure 2. Fractional OSL reading, $S(t)/S(0)$, vs. time, t, measured using five phones, plotted with the standard deviation on the result for all cups. A multi-exponential fit is shown.

carousels of cups: Phones 1–5 in the first carousel and Phones 6–11 in the second. The cups were read out without being dosed, and then irradiated with a dose of 0.8 Gy using the reader beta source and read out straightaway at room temperature for 30 s. The data for the unexposed phones showed good consistency, with a net OSL signal within normal background fluctuation for a sample of 10 resistors. However, two resistor samples gave a net OSL signal that was higher than this, i.e. 160 and 208 counts. Despite this, in dosimetric terms, none of the samples had a signal that would impact significantly on the overall dose assessment.

Net OSL signals (no preheat) for 0.8 Gy show wide variation in signal intensity, both for different resistor sets from within a phone, and for different phones (Figure 1). The data are plotted as the average of all the samples from a given phone; the maximum and minimum are also plotted. Two phones (1 and 5) showed good consistency for all sets of resistors but most showed considerable variation, the signal varying by an order of magnitude from the lowest value of one phone to the highest of another. Within a phone the inter-sample range was up to a factor of 2, larger than that observed by Beertens *et al.*(6), which is probably caused by these phones being from more different manufacturers and of a wider variety of ages.

The variation in the signal obtained from different phones (Figure 1) does not matter much, because each sample is self-calibrated, but a high sensitivity is preferred because it indicates that there is likely to be a good signal-to-noise ratio and detection limit. The cause of inter-phone variation is likely to be linked to different suppliers or batches of resistors, since the phones are from different manufacturers.

Fading

Following an accident or incident, it could be at least several hours before mobile phones would be available for analysis. During this time, fading of the OSL signal would occur. However, it would be highly problematic if the signal on the resistors from different phones showed very different fading rates: the self-calibration process corrects for the variable sensitivity (Figure 1), but quick results are required and fading could not be determined for each phone separately in an emergency.

To quantify the fading rate, the resistors from Phones 6–10 (Figure 1) were used to determine the fading characteristics. They were bleached by reading out at room temperature for 300 s, followed by a 0.8-Gy irradiation using the reader beta source. The cups were then left in the dark to fade, before being read out with no pre-heat at room temperature for 30 s(10). This bleaching and irradiation sequence was repeated for fading times of ~0, 1, 6, 12, 24, 48, 72 and 144 h. The OSL reading was then plotted against fading time (Figure 2) as a fraction of the OSL reading for ‘no fading’ (~0 h), the measurement of which began 18 s after exposure: the data are shown with a multi-exponential fit, which is found to fit these data well; the dose is stored in a range of different traps that will decay with characteristic half-lives, and so the true function could be of this form.

The variation between the fading for different phones (Figure 2) is smaller than the variation in sensitivity of the phones (Figure 1); this is fortunate for the dosimetry, which depends on fading being independent of the specific phone. However, this is a feature of the system that requires monitoring for a greater number of phones.

These fading data can be applied to the data for unexposed phones: the largest net signal on an unexposed phone (208 counts) would equate to ~0.05 Gy after 1 h of fading and 0.12 Gy after 7 d of fading. These are not considered significant readings for emergency dosimetry, but the undosed signal needs to be determined for a greater range of phones.

Detection limit

It is necessary to characterise the system in terms of the smallest dose it can assess so that its suitability for emergency dosimetry can be evaluated. This can be done in terms of the detection limit(11), D_L, which varies with the magnitudes of the OSL signal due to the applied dose (Figure 1) and the background OSL signal from a cup of bleached resistors. Since the signal due to the radiation dose fades with time (Figure 2), the signal-to-noise ratio deteriorates with time and hence the detection limit increases.

D_L for no pre-heat has been estimated from the data for the response at 0.8 Gy (Figure 1) and the fading curve (Figure 2), by assuming that the net signal is proportional to the dose received. D_L is calculated for the 99 % confidence level using the statistical fluctuations on the signal and background on the assumption that the counts in the PMT obey Poisson statistics (Figure 3). The data show that, up to 144 h, the average phone can be used to detect doses as low as 0.12 Gy. For the least sensitive phone studied here, this would rise to ~0.43 Gy. These detection limits are well below the dose level at which medical treatment would be required, especially for the more sensitive phones for which doses of 80 mGy could be detected 144 h after exposure.

These data for the detection limit are for optimal irradiation conditions. In practice, the phone may be carried in a pocket or a bag, with the source potentially highly distributed or discretely located. The geometry of the exposure will affect the magnitude of the whole-body dose, and the energy and type of radiation will also have an impact on the reading. These other factors hence contribute to the overall uncertainty, and so these data (Figure 3) represent the 'best case'.

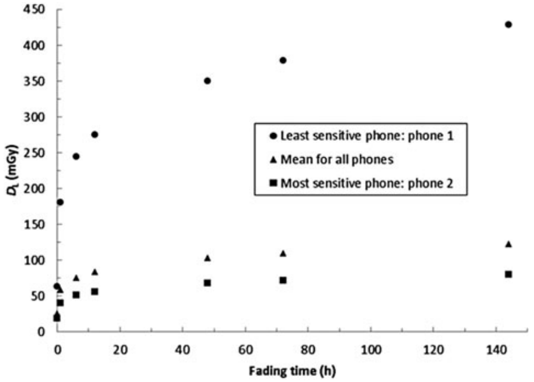

Figure 3. D_L versus fading time for different phones.

Irradiations on an anthropomorphic phantom

To investigate the effect of attenuation and backscatter from the body, irradiations of a mobile phone (i-mate Ultimate 8502) attached to the leg pocket region of an Alderson Rando anthropomorphic phantom(12) were performed. The phantom was exposed as uniformly as was achievable but, in a real exposure, the irradiation may be non-uniform, and so extrapolation to whole-body dose effects may be more difficult.

The ISO H-300 X-ray calibration photon field(13) with a quoted mean energy of 147 keV was used to obtain the high dose rates and doses needed to test the system: this was provided by PHE Radiation Metrology with an air kerma rate of 0.325 Gy h^{-1}. The dose rates available from radionuclide sources or the ISO wide/narrow fields were considered too low because irradiation of the whole phantom required a significant source–phantom distance.

The correct dose quantity for this experiment was considered to be 'whole-body absorbed dose'. Because no conversion coefficients are published for that quantity, and it is not even defined by ICRP, it has been approximated using the effective dose in this work. Since the $w_R = 1$ for photons and various methods of combining equivalent doses to produce an analogue of 'whole-body absorbed dose' showed deviations in the range −4 to +2.5 % relative to the effective dose, it was considered to be an acceptable surrogate. The intention was to assess the accuracy of whole-body dose estimates using a mobile phone, and so the personal dose equivalent was not considered appropriate.

Reference effective doses were calculated from the air kerma using the conversion coefficients from ICRP 116(14). The phantom was irradiated from the front with a reference air kerma at the centre of the front of the torso of 0.25 Gy, which corresponds to an antero-posterior (AP) effective dose of 0.32 Sv. The mobile phone was then changed, and the phantom was irradiated from the back with a reference air kerma of 1.15 Gy, which corresponds to a postero-anterior (PA) effective dose of 1.05 Sv. A higher dose was used for the irradiation from the back because the phantom was expected to attenuate the beam and hence give a smaller signal per effective dose.

Three sets of 10 resistors were extracted from within each phone and read out ~8 h after the midpoint of the irradiation time using the heating protocol for 60 s: the heating protocol was used to minimise the short-term fading effects during these long exposures. The delay in readout was used to simulate the delay in a real scenario, and also to further reduce the dosimetric impacts of the fading of the OSL signal, hence reducing possible uncertainties in the fading

Table 1. The mean effective dose from resistors extracted from the mobile phones (E_{phone}).

Orientation	E_{Ref} (Sv)	E_{phone} (Sv)	R_{phone}
Front (A–P)	0.32	0.88 ± 0.26	2.8 ± 0.8
Back (P–A)	1.05	0.84 ± 0.13	0.80 ± 0.12

The uncertainty on E_{phone} is the standard deviation on the result for all cups.

correction factors due to the relatively long irradiation times. For dose reconstruction, the fading curve developed by the MULTIBIODOSE project was used(10) and it was assumed that the fading time starts at the mid-point of the irradiation time. This is a reasonable assumption even for the higher dose irradiation: assuming instead that the fading time started either at the end or beginning of the irradiation would result in the dose estimate only changing by 2–3 % in this case.

The effective doses determined using the resistors from each phone (Table 1) show that the phone does not act as an optimal personal dosemeter when exposed AP, giving a 180 % over-response. This bias is probably caused primarily by the lack of tissue equivalence of the alumina substrate, which will cause it to absorb more dose from the X-ray field than it does for the ^{137}Cs field used for calibration. In practice, this will be somewhat offset by the under-response of 20 % when the person was exposed from behind.

DISCUSSION AND CONCLUSIONS

The PHE retrospective/fortuitous dosimetry service based on OSL of mobile phone resistors has been shown to have sufficient sensitivity for determination of doses to members of the public in a radiation emergency. Significantly, the sensitivity differences between phones do not appear to affect the fading characteristics. Work on the location of the phone needs to be extended to include more geometries and source energies. However, this initial work shows that this could be the cause of large errors in terms of either over- or underestimates.

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