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Retrospective dose assessment in a radiation mass casualty by EPR and OSL in mobile phones

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ABSTRACT

In the retrospective dose assessment of individuals potentially exposed to ionizing radiation after an accident, dosimetry with inert materials can complement or be used as an alternative to biodosimetry assays. Dosimetry based on physical methods such as Electron Paramagnetic Resonance (EPR), Thermoluminescence (TL) or Optically Stimulated Luminescence (OSL) provides measurements of absorbed dose in a variety of materials through the measurement of the radiation damage therein induced. Materials contained in personal objects can therefore be collected and used almost as physical personal dosimeters. Portable electronic devices (PED), i.e. mobile phones, MP3 players, watches, cameras, USB memory sticks, are very appropriate personal items because nowadays they are owned and carried by all groups of a large part of the population.
Here, we propose a combined system of dose measurements based on the use of EPR and OSL measurement of different components from the same electronic portable device (specifically mobile phones). Mineral glass used in window displays and alumina rich substrates contained in electronic components (e.g. resistors, etc.) used in the electronic boards acquire paramagnetic or luminescent properties under irradiation. The induced radiation damage can then be detectable by EPR and OSL. This work is carried out in the framework of the EU funded project Multibiodose with the objective to develop and validate methods for dose assessment specifically in a mass-casualties scenario.
The first part of this work was dedicated to: a) classify the types of glass and of electronic components according to their characteristics, b) estimate the related radiation sensitivity and the stability with time of the EPR and OSL signals. Seventy-five mobile phones of different brands and models were analyzed at three partner laboratory.

Keywords: retrospective dosimetry, population triage, emergency preparedness, EPR, OSL

1. INTRODUCTION

In the event of a large scale radiological emergency, the triage of victims according to their degree of exposure forms an important initial step. Retrospective dosimetric techniques are essential tools in the management of a radiological mass casualty and can provide timely assessment of radiation exposure to the general population. In this was identification of those exposed people who should receive medical treatment is possible (or feasible) (Ainsbury et al., 2010).

A number of dosimetric tools are currently in use or potentially available, but all of these must be adapted and tested for a large-scale emergency scenario. These tools are based on biological assay(s) (e.g. cytogenetics) or inert materials collected from personal objects (Fattibene and Wojcik, 2009). The methods differ in their specificity and sensitivity to radiation, the stability of signal and speed of performance

(Ainsbury et al. 2010). A large scale radiological emergency can take different forms. Based on the emergency scenarios, different biodosimetric tools should be applied so that the dose information can be made available with optimal speed and precision.

In order to increase the capacity of analysis, EC has funded the Multibiodose project which aims to develop multi-parametric assays for population triage (http://www.multibiodose.eu). In Multibiodose, assays are mainly based on biological samples (blood, skin), but the project also includes the analysis of inert materials (electronic components and mineral glass) from electronic pocket devices (e.g. mobile phone) by physical dosimetry techniques such as Optically Stimulated Luminescence (OSL) (Bassinet et al 2010; Woda et al 2008 and 2009; Beerten and Vahaevere 2008; Berteen et al 2009; Inrig et al 2008) and Electron Paramagnetic Resonance (EPR) spectroscopy (Bassinet et al 2010b; Trompier et al 2009 and 2011).

Herein, we report the first phase of the work, which was dedicated to the preparation of a database of the glass types used in the window displays and of the electronic components found on the circuit boards, according to the following criteria:

- characteristics of glass and electronic components,
- presence of a radiation induced signal,
- presence of a remnant radiation induced signal 10 days after irradiation,
- percentage of mobile phones (among those tested) having appropriate dosimetric characteristics.

2. MATERIALS AND METHODS

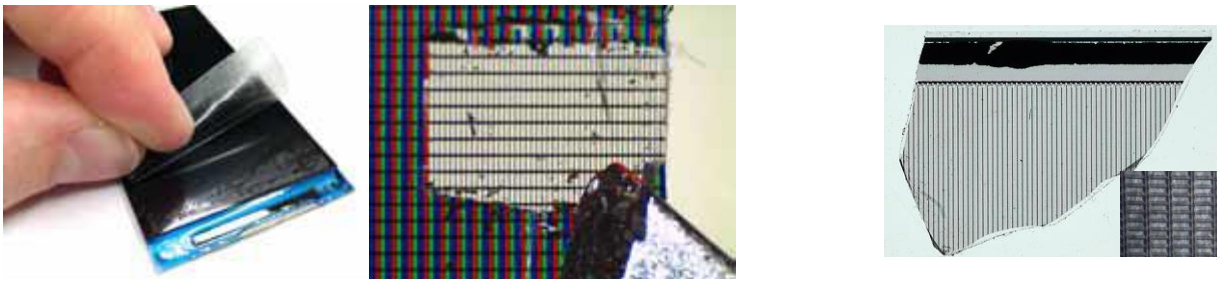
2.1 Criteria for the selection of mobile phones

Twenty-five mobile phones (MPs) of different brands and models were analyzed at each partner laboratory. In particular, 7 old generation NOKIA models already available at IRSN were distributed to the three partners and 18 different new models were bought at each laboratory. The total number of MPs was therefore 75, whereas the total number of models was 61 (because 7 were similar for the three partners). The first seven models were produced before 2009, whereas the remaining 54 models bought for the purpose of the present project were produced after 2010. Twenty four (i.e. half of the MP produced after 2010) were touch screen devices. For each MP the type and the number of electronic components (EC) present on the circuit board and the type of window display technology as well as the characteristics related to the MP (brand, model, manufacturing year) were collected.

2.2 Preparation and measurements of glass samples for the EPR analysis

MP window displays are presently based on liquid crystal technology (LCD). These displays have typically two glasses, between which there are the liquid crystals (Alternative suggestion: In these displays, a layer of liquid crystals is sandwiched typically between two glasses). For sample preparation, the two glasses were separated manually, the liquid removed firstly by using acetone, then by water and finally dried in air for a few hours. Touch screen windows usually have one or two additional glasses that, when present, did not need any cleaning. At least one of the display glasses in each MP was covered by electrodes in form of

extremely thin films either deposited on pellicles or embedded in the glass. In the technology currently most used, electrodes are made of metals whose presence hampers the EPR measurements. When the electrodes were deposited on a pellicle, this was removed by mechanical scratching (Figure 1). When the electrodes where embedded within the glass, they could not be removed and the sample was not measured.
The glasses were then crushed into fragments with a mortar and pestle. In one laboratory the glass was cut in regular rectangular pieces of 1x10 mm^2 dimension.



a) b)

Figure 1. a) Two phases of the preparation of the mobile phone glass for EPR measurements. b) Optical microscope 20x and 60x images of a glass fragment taken from a LCD window display. The electrodes grid is visible in both figures.

EPR measurements were performed with continuous wave X-band spectrometers. The spectrometers and the microwave cavities were different at the three laboratories and so the acquisition parameters were different as well. Measurements were performed before irradiation, 10 minutes after irradiation at 10 Gy and 10 days later to estimate the stability of the radio-induced signals.
The signal line shape of the non irradiated glass and of the 10 Gy irradiated glass were analyzed for each glass of the 75 displays. When scratching was not effective in removing the electrodes, the EPR measurement was not possible, because of the presence of metals in the samples. Nevertheless, for each MP at least one glass was measured at each laboratory and finally 121 samples of glass were measured.

2.2 Preparation and measurements of electronic components for the OSL analysis

The circuit board of a MP contains a variety of electronic components. Most of them contain a substrate of alumina rich ceramic that is sensitive to radiation and is detectable by OSL (Inrig et al 2008; Beerten et al 2008; Beerten et al 2009; Bassinet et al 2010; Ekendahl and Judas 2011, Fiedler and Woda 2011, Woda and Fiedler in prep). The components that were identified as suitable for OSL are resistors, inductors and capacitors because they have an uncovered surface of ceramics that can be measured by OSL. EC differ mainly in size, so that they have been classified according to their physical dimensions: large size (code: 0603, 1.6 × 0.8 mm), intermediate size (code 0402, 1.0 × 0.5 mm), small size (code 0201, 0.6 × 0.3 mm). No classification was made for capacitors because their size was very variable. Not all EC are present in all phones. Resistors and inductors of intermediate or small size are typically present in large quantities (>30 for intermediate resistors on a single board). This will allow measuring at least 10 EC in a single readout, thus improving the sensitivity. Small size EC are present in a smaller percentage, but the scenario might change rapidly with technology advancement. Capacitors were only occasionally found in newest generation mobile phones.

Components were mechanically extracted from electronic boards of 25 mobile phones and in one lab also cleaned in acetone in an ultrasonic bath for 15 min. The components were then placed with the radiation sensitive side facing upwards on cups of stainless steel, sprayed with a thin layer of silicone oil in order to avoid overturning during the OSL signal readout process.

With the aim of checking radiation sensitivity, every sample was irradiated at 10 Gy and measured 30 min after irradiation. Samples were again irradiated at 10 Gy and measured 10 days after irradiation to check the OSL signal stability over time. Moreover, in order to check (and correct for) the possible presence of sensitivity variations caused by irradiation and/or heating treatments, test doses (0.5 Gy for resistors and inductors, 1 Gy for capacitors) were delivered to samples after each 10 Gy irradiation –readout process.

OSL measurements were generally performed with ten 0402 components, unless less than ten of these components could be found on the circuit board. In this case, as many 0402 components as present were measured and an additional cup of twenty 0201 components (or as many 0201 components as available in case of less than twenty) was analyzed. The rationale behind this approach was to investigate whether a detection limit well below 1 Gy could be realized for an arbitrary mobile phone, using either an appropriate number or intermediate size components or a respective appropriate number of smaller size components as backup. Readout parameters used for 10 Gy and test dose irradiation are: preheating treatment at 120 °C for 10 s; blue light stimulation for 300 s at 100 °C; All labs involved used automated luminescence readers (models Riso TL/OSL-DA15 and -DA 20). Sample preparation and measurements, were performed under red light conditions. Measurements were performed under a nitrogen flux in order to reduce the presence of spurious signals in OSL decay curves.

Figure 2. A circuit board and two cups used for OSL measurements containing a capacitor and 20 resistors, respectively.

2.3 Sample irradiation

Samples were irradiated in air and at room temperature with a dose of 10 Gy with ^{60}Co sources. The OSL reader available at HMGU was equipped with an internal ^{90}Sr source which was used for sample irradiation.

3. RESULTS

3.1 EPR in glass samples

The analysis of the signal line shape of the non irradiated glass and of the 10 Gy irradiated glass of the window displays of the 75 MP led to the identification of five main typologies of EPR spectra. EPR spectra were classified with codes I-V and are illustrated in Figure 3. The percent of availability of types I, II and III was roughly equally distributed (around 30%) among the models of LCDs measured. Type IV was found only in the touch screens. Only 3 glasses of type V were found. About 20% of samples could not be measured because of the presence of metal electrodes deposited on/in them and this will require further study and improvement in the sample preparation methodology.

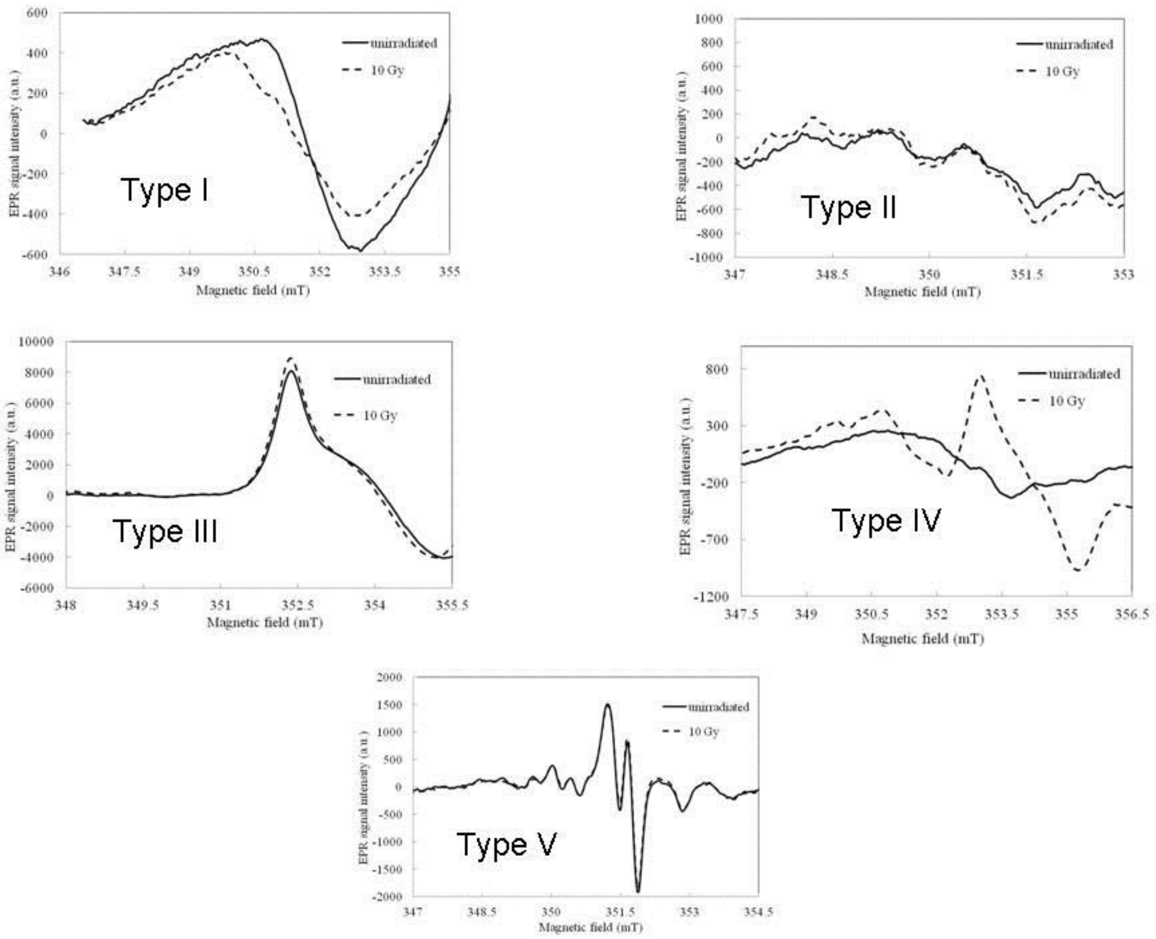


Figure 3. EPR spectra of the five types of glass identified in the MP measured in the present project. The spectra before irradiation and 10 min after a 10 Gy irradiation are shown.

From the measured spectra it is possible to derive the following conclusions:

- all types of glass presented an EPR signal before irradiation
- in 4 types (I to IV) out of 5, changes in the signal were observed after irradiation
- in type V no effect of radiation was detected.

The observed EPR spectra seem complex and composed of various signals, i.e. they are likely generated by various radical species. From this preliminary analysis it appeared clearly that spectrum simulation fitting will be necessary to decompose the spectra and to identify the radiation induced component. However, the radiation induced signal was clearly specific of irradiation, i.e. different from the signal observed in the non irradiated sample, in two types of glass (codes I and IV) and we suggest that these are used for dose assessment.

All samples were measured again 10 days after irradiation. The signal was still detectable in all glass samples 10 days after irradiation. In some glasses a loss of signal up to 20% was observed after 10 days. In other glasses the signal loss was not detectable or was within the measurement uncertainty. As abovementioned, the EPR spectrum is probably composed of various components. It is likely that the EPR spectra are composed of stable and unstable components unresolved at this stage of the research. Spectrum simulation fitting will be used in the second year to distinguish the components and to identify the ones that are stable in time and therefore are more appropriate for the retrospective dosimetry. A summary of results is reported in Table 1.

Table 1. Summary of the properties of the five types of glass identified in the 61 models of MP investigated in this project.

Code	**Present in**	**Radiation sensitive (Y/N)?**	**Radiation specific (Y/N)?**
I	LCD and touch screen	Y	Y
II	LCD	Y	N
III	LCD	Y	N
IV	Touch screen	Y	Y
V	LCD	N	-

3.2 OSL in electronic components

All resistors, inductors and capacitors showed a very intense OSL signal after irradiation with 10 Gy. An example is given in Figure 4 showing the OSL decay curves of a sample of ten 0402 resistors unirradiated and irradiated at 10 Gy, 30 min and 10 days after irradiation.

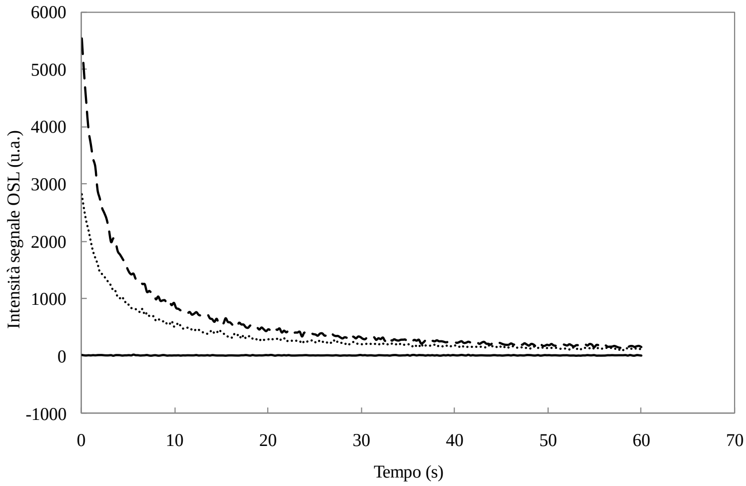


Figure 4. OSL readout curves of a sample of ten 0402 resistors: unirradiated (solid line), irradiated at 10 Gy and measured immediately after irradiation (dashed line) and irradiated at 10 Gy and measured after 10 days (dotted line).

In Table 2, a summary is given on the OSL properties of the electronic components, as investigated in the three laboratories. Inductors and capacitors show the highest and lowest radiation sensitivity, respectively. The minimum detectable dose was estimated by calculating the average and standard deviation of the OSL signal of all 25 unirradiated samples in each lab and then calculating the dose corresponding to three standard deviations for each sample. A detection limit lower than 1 Gy was found for all components, although with some differences, depending on the type of component and on the size and number of components available. Out of the 61 different mobile phone models, only in seven less than 10 (between 0 and 7) resistors of intermediate size (0402) could be found. However in these cases there were always more than 20 smaller size resistors (0201) of sufficient sensitivity available. Because components, if both sizes are taken into account, are therefore present in sufficient number in all mobile phones, it can be concluded that radiation potentially can be detected by OSL in 100% of all mobile phones.

The OSL signal of irradiated electronic components was still clearly detectable 10 days after irradiation. In all samples a signal loss was observed and the mean value of remnant signal was 50%. Generally, resistors seem to display a more homogeneous fading rate than inductors. The component with the least signal loss (around 30%) was the small size inductors, although it has to be noted that this was observed only on a small subset of 12 samples and would need further verification.

Table 2. Summary of OSL dosimetric properties found on electronic components in the three laboratories. Numbers in the second and third columns are averages; ranges represent minimum-maximum values observed.

Type / number of items for 1 meas.	**Average of signal increase (a.u./10 Gy)**	**Minimum detectable dose (mGy)**	**Signal 10 days after irradiation (%)**	**Availibility over the 75 phones (%)**
Resistor 0402 / 10	5.05 [2.5-8.5]	30 [17-55]	53 ± 5	100
Resistor 0201 / 20	1.33	80 [70-100]	50 ± 3	50
Capacitor / 1-5	0.71 [0.5-5.0]	200 [80-300]	53 ± 3	50

Inductor 0402 /10	25.05 [3.0-84.0]	8 [1-15]	53 ± 10	90
Inductor 0201 / 20	54.5 [40.0-67.0]	24 [9-36]	74 ± 4	30

4. CONCLUSIONS

With EPR, five different types of glass were identified, three in LCD, one in touch screen of smart phones, and one both in LCD and touch screen. In each mobile phone, depending on the technology used, from 2 to 4 glass plates were available. Amount of glass available exceeds largely the quantity needed for EPR measurements. From the EPR database, in most of MP, glass plates are usually made of different types of glass. We have found that 86 % of the MP's has at least one glass plate made with glass sensitive to radiation. Most the samples exhibit a signal before irradiation, some would require to develop deconvolution procedure. Thus, it was not possible at this stage of the work to evaluate the minimum detectable dose. Most of glasses exhibit some radio-induced components with almost no signal loss in the considered delay. That's probably one of the main advantages of the EPR on glass, with the possibility to repeat measurement since EPR is a non destructive measurement method.

On the circuit boards, five different types of electronic components were selected for this work. All the phones use in the study have at least one of these components, therefore making it conceivable to assess dose in most of MP available on the market. The selected EC do not exhibit a detectable signal before irradiation which simplify the signal analysis. The minimal detectable dose was estimated to be lower than 200 mGy for all the EC studied, which is largely below the threshold usually considered for population triage (~1 Gy). The main drawback of this assay is the instability of the OSL signal (about 50% loss in 10 days), so that correction for signal fading becomes necessary which requires the knowledge of the time of the exposure.

The first part of the work performed in the Multibiodose project has shown that the EPR/OSL measurements of inert materials from mobile phone offer high potential to develop population triage capacity.

A comparison exercise is planned this year. The comparison will include European laboratories external to the project through the EURADOS network and will be performed for both EPR/glass and OSL/electronics methods. This exercise aims to disseminate the protocols developed in Multibiodose for the two assays and to evaluate the possibility of external laboratories to assess doses correctly by applying these protocols. Glass plates and EC irradiated with unknown doses will be distributed to the participants. These new assays are implemented in the new project RENEB funded by EC, aiming at developing a sustainable European network in biological and physical dosimetry for population triage, that guarantees high throughput and reliable results (see IRPA13 2366048 presentation and paper).

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