EXPOSURE MEASUREMENTS ON PORTABLE X-RAY FLUORESCENCE SPECTROMETERS

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Abstract. Portable X-ray fluorescence spectrometers (XRF) are more and more used for the verification of alloys in metallic materials, heavy metals in plastics and other applications. Documents on portable XRF which have been available until now show high dose rates at the exit window of the spectrometers. However, these values are often not traceable. There is lack of information on how the values were measured or inadequate electronic measurement equipment has been used. To verify these dose rate values the authors measured six portable XRF with thermoluminescent dose meters in combination with an Alderson phantom. At operating parameters of 40 kV and 50 µA, for example, an extremely high dose rate of 76 Sv/h in the primary beam had been determined. In recent years, hazards have been underestimated so far. The measurements, the results and the consequences for protection measures will be presented and discussed in the presentation.

Key words: X-ray fluorescence spectrometer, dose rate, thermoluminescent dose meter,

1. Introduction

The XRF sent a primary x-ray on the probe. The backscattered fluorescence radiation will be analyzed in the XRF with regard to the energy and intensity. This information leads to the composition of the alloy. The dose rate in the primary beam could be extremely high. Therefore radiation protection measures have been implemented in the construction of the XRF's.
The question was, what hazards could occur in case of malfunction of these protection measures or if the XRF are not used in appropriate manner - especially if the probes would be hand-held illegal. To verify this, the radiation protection department of the German Social Accident Insurance Institution for the Energy, Textile, Electrical and Media products Sectors (BGETEM) together with the district government of Cologne assayed six different XRF. During these measurements the protective gear had been taken out of operation.

2. Materials and Methods

The primary beam of portable XRF's is hardly focused. This is the main reason why electronical measurement equipment with a bigger measurement volume is only useful to localize the intensity maximum. Therefore it was decided to measure with very small thermoluminescence dose meters (TLD). Commercially available TLD-100 chips, containing LiF:Mg,Ti, were used. The energy-range of these TLD is between 10 keV and 10 MeV and the dose-range between 1 µSv and 10 Sv.
At each measurement position, two chips with 3.2 mm diameter and 0.05 mm thickness were arranged close to each other (see figure 1) in a lightproof foil, so that two independent values could be obtained at every position.
The thermoluminescence readout equipment was a manual planchet reader, type H3500. The calibration of the TLD was done at the PTB in Braunschweig using an average energy of 25 keV according to the suspected radiation energy. Underground measurements were taken into account and subtracted from the measured values. All results are values of the photon-equivalent-dose-rate. Regarding the interesting person dose, and in order to have realistic conditions, the TLD's have been mounted on the surface of an Alderson phantom for backscattering purposes (see figure 2).

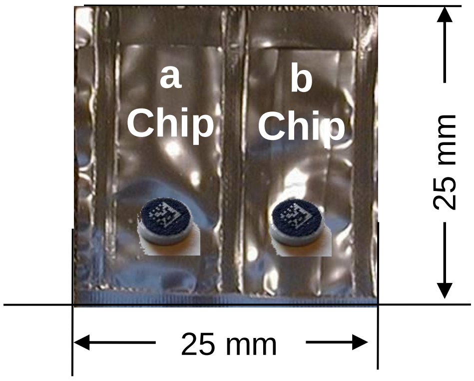

figure 1: arrangement of the TLD at one measurement position

figure 2: measurement with an Alderson phantom

2.1 Description of the XRF's

All investigated XRF's have different protection measures to prove if the probe is directly in contact with the exit window. The x-ray could only be emitted if the XRF is fitted on the probe surface. This is secured by proximity switches, infrared sensors or the intensity of the backscattered radiation. In some cases several of the mentioned alternatives have been realized. Some of the XRF'S had filter systems, some not. If filters were used, they changed automatically, depending on the backscattered radiation. The anode material was different. All XRF's are equipped with signal lamps indicating if x-ray is emitted or not, but the number and position of these lamps are different.

For detection purposes of the backscattered radiation diodes were used predominantly. But the diodes bear only a limited dose rate, which requires filtering of the primary beam. To reduce the analyzing time other detection systems were used, which can sustain a considerably higher dose rate. To start the x-ray emission some XRF need a steady push on the button. But some devices need only a single action and emit x-ray after release the button until the analysis had been done. Almost every producer offers special protective housings for the analysis of smaller probes. Radiation protection collars are also available optionally.

For the measurements always the maximum voltage (40 kV - 50 kV) and current (20 µA – 100 µA) was chosen. The used values have been reported in table 1 below.

All protection measures have been deactivated for the measurements. In order to do this special software procedures are necessary which could only be realize by the producer and which are protected by a password or a key.

2.2 Measurement positions

An array of eleven different measurement positions had been arranged: The XRF's were fitted on the surfaces of steel-, aluminum- and Plexiglas- probes so that the exit window of the XRF had a distance to the dose meter of 150 mm (figure 2). The same three probes had been used with the XRF's tilted slightly to the surface of the probes (figure 3). Both arrangements have been chosen to verify the scattered radiation intensity.

Another series of measurements were dedicated to the dose rate of the primary x-ray beam in distances of 0 mm 100 mm, 500 mm and 1000 mm (figure 4) to the exit window. In the end a set of measurements was done under a wooden table with 30 mm thickness (figure 5) to verify the dose for the legs if somebody use the XRF in sitting position (figure 6).

figure 3: scattered radiation on
Acrylic glass, XRF tilted

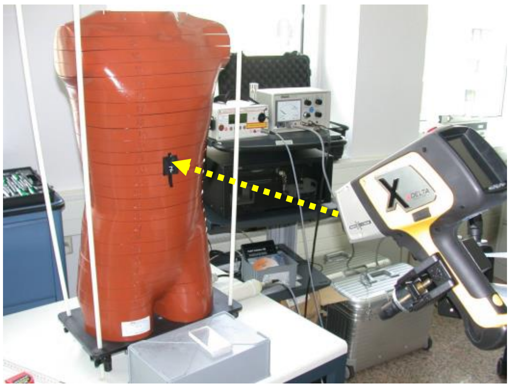

figure 4: primary beam, dose meter
fixed in 100 cm distance

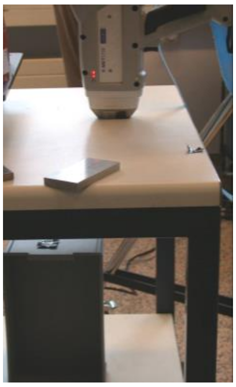

figure 5: primary beam measurement
under a table

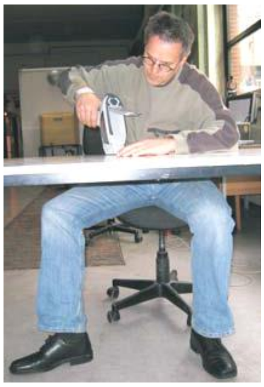

figure 6: operator sitting on a
wooden table

3 Results

A comparison between the TLD measurements and the test measurements with electronic devices close to the exit window clearly show that the electronic devices are not capable for this kind of measurements, because the hardly focused beam did not radiate the measurement chamber homogeneously. There was a good compliance between these results in greater distances from the exit window. All TLD-results for the scattered radiation were below the detection limits. The TLD-results for the primary beam measurements are reported in table 1.

The dose rate results for the different distances from the exit window clearly show the expected behavior of inverse quadratic relationship. The highest dose rate was about 76 Sv/h at the exit window. The different results at that position are in good compliance with the theoretically determined dose rates calculated with the values in 1000 mm distance. The values in 100 mm distance did not always fit perfectly. The reason for that may be the difficulty in finding the dose rate maximum of the hardly focused beam. It is remarkable, that the results did not correlate with voltage or current because other parameters like filtering and anode material were different.

XRF	voltage (kV)	current (µA)	maximum dose rate of the primary beam [mSv/h] by distance r from the exit window				
			r = 0 cm	r = 10 cm	r = 50 cm	r = 100 cm	under table r = 24 cm
1	50	40	570	31	1.2	0.2	1.6
2	40	20	1564	229	15.0	3.6	0.1
3	40	100	650	26	1.4	0.3	1.9
4	40	50	75683	2385	91.0	20.0	4390.0
5	45	40	2240	152	11.0	2.6	12.3
6	50	50	38240	175	66.5	15.7	30.9

Table 1: TLD-results fort he dose rates in primary beam

3. Discussion

The TLD-measurements on portable XRF have shown that through malfunction of the protection measures or if the XRF are not used according to instructions - especially if the probes would be hand-held - even after a few single analyses extremely high doses for the hands are possible. If the XRF are often used in this way, deterministic casualties of the skin could occur in connection with a greater risk for skin cancer. The measured dose rates at the exit window of the XRF's were between about 0.6 Sv/h and 76 Sv/h. Small probes should be analyzed in special protective housings and never be held with the second hand.

For the described measurements all protection measures have been deactivated and the voltage and current has been set to the maximum parameters. The normal user of the XRF does not have the opportunity to do this, because this is password secured. The discussed results are a WORST-CASE situation in case of malfunction or malpractices. If any precaution works the annual dose for the operator is surely below one mSv. Surveillance with dose meters doesn't make sense with regard to the fine focused beam even for finger dose meter.

If the XRF were used in sitting position at a table or at an assembly line there is the hazard of higher exposure of the legs. The measured dose rates under a wooden table were between 0.1 mSv/h and 4.4 Sv/h. In these cases constructional protection should be planned.

In addition to the constructional protection measures a good safety instruction of the operators is of importance. The operator should prove the protection measures periodically dependent on frequency of use. Safety distances for third persons should be determined.