

Radiation exposure to handheld XRF operators analyzing glass

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Introduction

The number one aim in radiation safety is to keep exposure as low as is reasonably achievable (ALARA). Still, there exist international [1] and national [2,3] regulations on occupational radiation safety, as well as institutional policies (e.g., [4]) limiting the amount of radiation a person should be exposed to in their work. Operating a handheld/portable x-ray fluorescence (XRF) spectrometer is not generally considered a highly risky endeavor in terms of radiation exposure, yet there is frustratingly little data available on the subject [5]. This paper shares data from a real-life practical application and compares the radiation levels to an international safety standard, in order to contribute data where there seems to be a relative dearth, so that handheld XRF operators might inform themselves more fully about the risks associated with their work. This paper is limited, however, in that the tests are carried out on one type of material (glass) with one instrument with limited settings and at relatively infrequent intervals (every 10 s), as the aim was to gain a general idea of the radiation exposure in advance of a specific series of planned tests. If radiation exposure is of particular concern to an individual operating handheld XRF, or if exposure needs to be monitored for any reason, the operator should wear a dosimeter and/or conduct tests with their own XRF instrument, using their own normal operational settings, on materials related to their samples and research.

The tests reported in this paper were partly motivated by the general lack of data, but were also completed as part of the development of a customized attachment for handheld XRF that allows the quantitative or semi-quantitative analysis of window glass, in particular

where the window pieces are too small to accommodate the full size of the spectrometer's face [6]. Medieval stained glass windows, particularly, are characterized by small glass pieces encased in lead comes. The inability to put the spectrometer flush on the glass surface creates distance between the sample and spectrometer that varies from sample to sample, resulting in the reduction of the measured intensity to varied degrees and disrupting the accuracy and precision of the results. The purpose of the attachment, therefore, is to maintain a constant distance between the sample and detector, so that good precision is preserved and the resulting decrease in measured intensity could be corrected through empirical calibration [7]. The attachment, nicknamed the WindoLyzer, was 3D-printed in a material composed of very light elements (polylactic acid, C₂H₄O₂), which would not interfere with analysis but also would not attenuate scattered x-rays. Because of the distance and the lack of attenuation, it was anticipated that the use of the WindoLyzer attachment might increase radiation risks to the operator, necessitating health and safety tests.

Method

The measurements were made using a standard Geiger counter to monitor the radiation dose rate (in μSv per hour) during operation of a handheld XRF. The XRF employed in this research was an Innov-X/Olympus Delta Premium spectrometer (DP6000CC), which has a Rh anode, a silicon drift detector, and a spot size of 10 mm. The built-in program called "Soils" was used, as this mode is optimized for oxygen-rich matrices and uses Compton normalization for quantification. The Soils mode uses three so-called beams, or settings with different combinations of primary radiation voltage, current and filters, which run sequentially. Beam 1 operates with a 40 kV accelerating voltage, 89 μA tube current, and a 1.5 mm copper filter; Beam 2 uses a 40 kV accelerating voltage, 52 μA tube current, and a 2.0 mm aluminum filter; and Beam 3 runs with a 15 kV accelerating voltage, 68 μA tube current, and a 0.1 mm aluminum filter. Each "beam" was operated for 20s. As the scatter of x-rays from a handheld XRF is highly dependent on the material being analysed [5], a small, modern stained glass panel (within its lead comes) was used as the analysed material during these tests.

The measurements were taken at various points relative to the spectrometer's nose to determine how the operator's position relative to the instrument as well as the degree to which the use of the WindoLyzer attachment affects dose. The operator is unlikely the stand directly in front of the spectrometer while it is running, but it is possible the operator may stand adjacent/parallel to the direction of analysis (for example, using the spectrometer on a table-top, face downwards towards the sample) or behind it (holding the spectrometer facing away from him/her, **Figure 1**). Therefore, the areas that were measured were 20 cm and 40 cm to

the right of the spectrometer and 50 cm behind the spectrometer (measuring from the nose), which is the approximate distance of the analyst's torso if using the spectrometer handheld. Measurements were recorded every 10 s throughout the 60 s analysis. The tests were repeated using the WindoLyzer, and again using the WindoLyzer with a lead shield surrounding the spectrometer's nose.

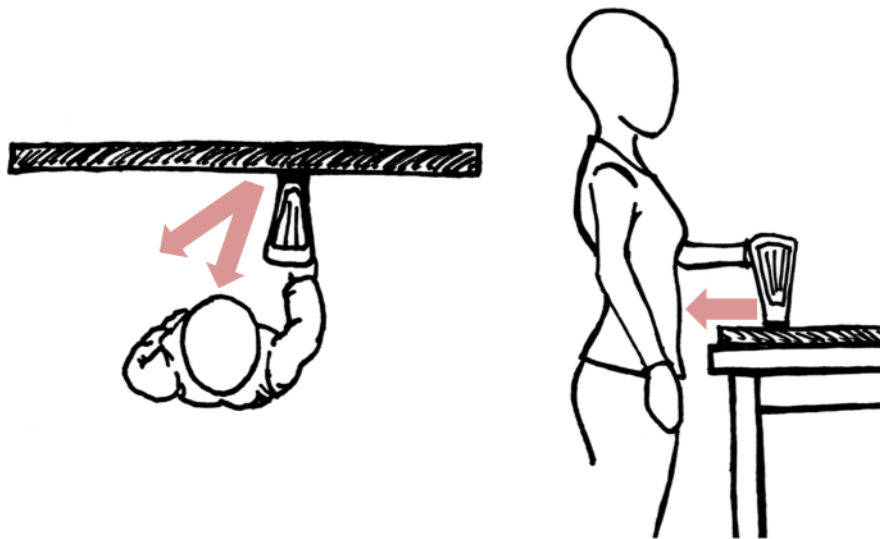


Figure 1. Two areas of radiation risk to an analyst using handheld XRF to study a stained glass panel: when using a vertical lightbox or stand, the analyst is behind the spectrometer (left); while for tabletop analyses, the analyst is adjacent to the spectrometer's nose (right).

Results

The results of these health and safety tests are reported in **Figure 2**. The maximum dose rate measured using the spectrometer normally (without a WindoLyzer or lead shield) was 4.4 $\mu\text{Sv/h}$ and was measured 20 cm to the side, at 40 s. As expected, doubling that distance approximately quartered the dose rate: the maximum dose rate measured using the spectrometer normally at 40 cm to the side of the spectrometer was 1.0 $\mu\text{Sv/h}$, at 40 s. Using the WindoLyzer without a shield resulted in much higher dose rates (18.1 $\mu\text{Sv/h}$ measured at 40 s, 20 cm to the side; 3.4 $\mu\text{Sv/h}$ measured at 40 s, 40cm to the side), while adding a lead shield to this set up lowered the dose rates to the same range as normal usage. The position behind

the spectrometer resulted in the lowest dose rates, with all measurements remaining below 0.6 $\mu\text{Sv/h}$ and with little difference observed between the different configurations.

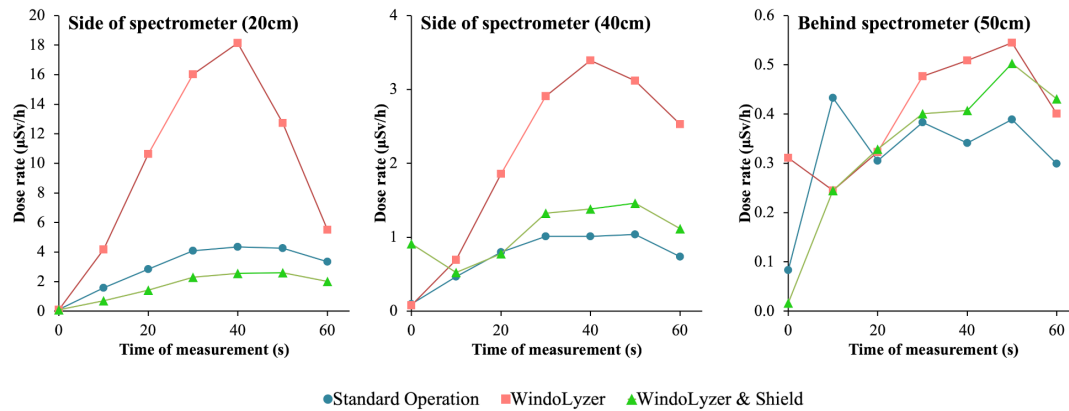


Figure 2. Graphs showing the radiation dose rates detected by a Geiger counter at intervals throughout analysis of a stained glass panel by handheld XRF. The background measurement (taken immediately before operating the spectrometer) is reported as $t=0\text{s}$.

Discussion and Conclusion

Regardless of the apparatus, the safest position for the operator appears to be behind the spectrometer; but in the case of tabletop analyses, a lead shield might be used to further reduce radiation exposure to the operator, particularly when non-standard set ups are employed, such as the use of the 3D-printed WindoLyzer attachment.

To compare the amount of radiation detected in these tests to the dose limits set forth by international, national or institutional regulatory bodies, the radiation rates reported by the Geiger counter (in μSv per hour) must be transformed to an absorbed dose by establishing the number of hours over which the exposure occurred, and the absorbed dose must then be converted to the effective dose, or whole body dose equivalent. The effective dose is a function of the absorbed dose, the type of radiation, and the type of body tissue where the radiation occurred, and can be calculated according to the equation and constants [5]:

$$E = W_T \cdot H_T \cdot W_R$$

where E is the effective dose, W_T is the tissue weighting factor (0.01 for skin), H_T is the absorbed dose to the tissue, and W_R is the radiation weighting factor (dependent on the type

of radiation: 1 for x-rays).

The effective doses for analyzing a glass panel directly on the surface and with the use of the WindoLyzer (with and without a lead shield) are reported for different periods of exposure in **Table 1**: first, for 21 hours, which was the estimated time of handheld XRF operation over a three-day case study [6,7]; second, for 260 hours, equivalent to one hour of use per working day, an estimation of an analyst's annual use (compare to [5]); and finally, a more extreme case, 1820 hours, or 7 hours per working day. Although the dose rate varied, these calculations are based upon the assumption that the maximum dose rate measured during the above tests were sustained throughout the 60 s of analysis.[1] The International Atomic Energy Agency (IAEA) publishes a safety standard with dose limits for occupational radiation exposure as well as public exposure, which are also given in **Table 1**[2]. Analysts and employers should also refer to their government's national regulations as well as institutional regulations. For example, UCL, where this work was undertaken, has a policy to investigate an effective dose above 200 μSv and advises that radiation exposure be kept as low as reasonably achievable [4].

	Standard Operation		WindoLyzer		WindoLyzer and Lead Shield	
	20cm side	50cm behind	20cm side	50cm behind	20cm side	50cm behind
$\mu\text{Sv/h}$ (max. measured)	4.4	0.43	18.1	0.5	2.6	0.5
Effective (whole body) dose equivalent (μSv)						
21 hours (three-day case study [6,7])	9.1	0.9	38.1	1.1	5.5	1.1
260 hours (1 hour/day annually)	113.2	11.3	471.4	14.2	67.7	13.1
1820 hours (7 hours/day annually)	792.2	78.8	3299.7	99.2	473.7	91.5
IAEA annual effective dose limit for occupational exposure (μSv)			20,000			
IAEA annual effective dose limit for public exposure (μSv)			1,000			

Table 1 Annual whole body dose equivalents for different use parameters of handheld XRF analysis on stained glass panels, for different hours of usage per year. 21 hours is the estimated hours of use during an analytical trip to Canterbury which took place over 3 days; 260 hours was an annual usage estimate used by Rouillon et al. [5] (1 hour per week day); and 1820 hours is an extreme case of 7 hours per week day.

Most of the calculated effective doses in **Table 1** do not exceed even UCL's limit for

investigation (200 μSv); only when using the WindoLyzer without a shield and standing 20 cm from the side of the spectrometer for 7 hours/day annually does the dose (3,300 μSv) exceed the IAEA limit on public exposure (1,000 μSv), but still does not approach the limits for occupational exposure to workers (20,000 μSv). Standing behind the spectrometer is the safer option, as even at the most intensive usage the annual dose remains below 100 μSv . 260 hours per year (1 hour per week day, or about 37 days of 7 hours constant use) would result in an effective whole body dose of 14 μSv , well below all limits.

In the effort to keep radiation exposure as low as possible, it is advisable to use a lead shield for tabletop analyses, and if possible, use a supporting structure such as a small tripod to hold the spectrometer so that the analyst can step back during operation. Similarly, when analyzing materials that have been secured in an upright position (as in **Figure 1, right**), the use of a full-sized tripod not only alleviates the strain on the analyst's arms and the risk of pressure on the sample, but also allows the analyst to step back several paces during analysis, greatly reducing exposure.

References

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[1] This assumption was made in order to characterize the worst-case scenario by overestimating the radiation exposure to the user, so that if the calculated exposure is still within regulatory limits, the user may feel confident in their health and safety.

[2] Note that (1) further restrictions apply for workers who are pregnant, breast-feeding, or under the age of 18; (2) additional dose limits are given for exposure to different parts of the body; and (3) there are some variations on the limits that allow higher doses, for example: the dose limit for occupational exposure is actually given as an average of 20 mSv per year over five years, not to exceed 50 mSv in any given year.