

As the responsible project manager, how would you approach the process of introducing a specified new piece of equipment (such as a survey unit or microscope) for use by your team, and what measures you would take to ensure that it was being used correctly and safely (documentation, training and monitoring)? (40%, 3500 words or equivalent)

One piece of equipment that is useful for a large archaeological unit with the quantity of sites and finds to warrant it, is an x-ray machine. X-raying objects can aid in their identification as it allows for details to be seen beneath the corrosion layers and allows for a permanent visual record of an object that is inherently unstable (Historic England 2006, 3); most museums have a requirement that metalwork be x-rayed prior to the archive deposition (e.g. London, Bedfordshire, Hertfordshire, Norfolk, Staffordshire (Museum of London 2009; Bedford Museum 2010; Hertfordshire Museum 2017; Norfolk Museums Service 2018; The Potteries Museum & Art Gallery 2019) etc.), and having a machine on-hand will make the process easier and cheaper in the long-run. This assignment will look at the process of introducing a small x-ray cabinet and the measures a project manager would take to introduce one to a team and how they would ensure it is being used correctly and safely.

In summary, introducing an x-ray machine to an office requires several steps. These steps include discussions between key team members, health and safety representatives, and the manufacturing company to ensure that the device meets the requirements needed by specialists and that it can be done safely. As part of this several key documents will need to be produced including a risk assessment, a written guide explaining the procedure on using the machine, safety check documents and a usage record. The appointment of a radiation protection supervisor who will oversee the use and any monitoring of the equipment; and the training of staff in radiation awareness will need to be completed before any use of the equipment. This essay will look at these in a chronological overview from deciding it might be worth investing in an in-house x-ray machine to its introduction to the team and its use.

Firstly, research into the requirements of x-radiography for archaeological artefacts should be conducted. The relevant team members should be consulted for this as early as possible with conservators and finds specialists – namely metalwork or small finds, but ceramic, osteologists, and zooarchaeologists as well as an archivist – to ensure that the device purchased would meet the requirements of each specialism in terms of image quality, size of the x-ray area, and any archive requirements. By allowing the relevant team members to be engaged early in the process the project manager would ensure that the equipment purchased would be fit for purpose and meet the minimum requirements of each specialism and the final repository. Once the minimum requirements have been decided, the next step would be to research the types of machines available that meet these requirements to get an idea of the size of the machines, their initial costs and maintenance requirements. X-ray cabinets can be custom-built (Euroteck) to the required specifications and space availability. At this point it would be beneficial to contact the person responsible for facilities to evaluate good options for where the device could be placed and the maximum measurements the device could be for the different spaces. When deciding to purchase a machine there are various types of x-ray machines to be considered: analogue, computed (also known as indirect digital), or direct digital radiography. Analogue radiography will use x-ray film to capture the image, computed radiography uses a photostimulable phosphor plate which is then

scanned and converted to a digital form, digital radiography where x-ray energy is directly converted to electrical signals (Bansal 2006, 425; Cofield and Doub 2020, 39). Direct digital radiography produces a lower dose of radiation per use than both analogue and computed radiography (Odell (Ed) 2010, 138; Bansal 2006, 428; Preferred Urgent Care 2018) and is preferred due to the lower exposure risk and also a lower labour input requirement allowing for more images to be taken daily with no additional exposure risks, and lowers storage requirements for the images as they would not have to be stored in a physical location (Bansal 2006, 428); direct digital is also able to provide higher image quality (Varex Imaging 2016). Digital radiography is, however, the most expensive (Thomas 2018; Intriquip 2021) so the cost would have to be weighed against the labour requirements, the image quality required by specialists and conservators, and the exposure risk. Direct digital radiography would be preferred because of the lower dosage per use and the streamlined process, however the choice between direct digital and computed radiography would likely be dependent on budget availability.

Prior to the installation of the cabinet, it would be beneficial to discuss with the manufacturer and the in-company health and safety team about the associated health and safety risks with using the cabinet such as risk of radiation exposure. The annual average exposure of radiation to people in the United Kingdom is 2.7mSv with the maximum exposure limit for those working with nuclear energy being 20mSv/y (UK Health Security Agency 2011); long-term exposure and/or high levels of radiation can affect health to varying degrees from skin redness, hair loss, acute radiation syndrome, and cancer (WHO 2016). Care will need to be taken to limit the levels of exposure to the radiation, communicating with the designers of the cabinet about expected levels of radiation users can expect to face and what measures can be implemented to reduce this if necessary. Cabinets will have built in safety measures to prevent or reduce radiation exposure including “engineering controls, design features, safety features and warning devices” (The Ionising Radiation Regulations 2017, sec.9). Radiation from an x-ray cabinet is minimal coming to <0.5µSv/h (micro Sieverts per hour (Radiation Protection Service 2018, 3; University of Exeter 2018, 2)) which, after calculating the yearly cumulative dose, is well below the exposure limit where the radiation starts to affect people’s health (100mSv (UK Health Security Agency 2011)). Yearly cumulative dose is calculated by taking the exposure dose and multiplying it by the hours and days¹ of exposure (Hatamura 2015, 135) – in the case of x-ray cabinets the yearly cumulative exposure is <1mSv/y if one were to stand directly next to the x-ray machine every working day, for the full working day. For comparison, flight and cabin crew, on average, are exposed to 2.4mSv/y (Watson et al. 2005, 44; Oatway et al. 2016, 7).

$$\frac{0.5\mu\text{Sv/h} \times 7.5 \times 254}{1000} = 0.95\text{mSv/y}$$

This level of cumulative exposure would mean that personal protective equipment (PPE) would not be required by staff. Regardless, legally a risk assessment should be completed (The Management of Health and Safety at Work Regulations 1999, sec.3.1; The Ionising Radiation Regulations 2017, sec.8): one should be created specifically for the machine purchased outlining the expected radiation levels from the machine, the cumulative exposure limit, and the safety measures on the equipment itself, as well as the possible hazards, their control measures and their risk to the employees who will be using the machine; and have reference made to this on the overall office risk assessment with hazards and risks for those who will not be near or using the machine. These risk assessments should

¹ Hours taken from the working day for MOLA, and working days in a year taken from the calendar year for 2024 (Work-Day 2023)

be drawn up prior to the instalment of the cabinet so that the relevant team members can familiarise themselves with the risks and can highlight any concerns they may have so they can be addressed prior to the hazard being introduced. In addition to the risk assessment, a written guide (or 'local rules') that outlines the working instructions that staff will be expected to follow to restrict exposure; this document should also name the team member(s) assigned as the radiation protection supervisor(s) and be readily available to all staff who will use or be in the vicinity of the x-ray machine (The Ionising Radiation Regulations 2017, sec.18), though section 18 does not apply here as the expected level of cumulative radiation is $<1\text{mSv/y}$ and therefore the area does not need to be designated as a controlled or supervised area (The Ionising Radiation Regulations 2017, sec.17) it would be a good idea for staff to see the company taking health and safety above the minimum required by law. Furthermore, a manual should be written (more details below) outlining the procedure of x-raying artefacts including what should be x-rayed, when artefacts should be x-rayed, who should be using the x-ray machine, what training staff need, who is responsible for the safety checks, how someone actually uses the x-ray cabinet and what records need to be kept relating to the use of the machine. Ideally, these documents would be produced in conjunction with the risk assessment as they will inform each other, and information will overlap. It cannot be overstated how important keeping staff safe from radiation risks and ensuring they have the relevant training to carry out this work safely, is. Although these documents should be written prior to the machine being installed in the workplace, it would be preferable that they be reviewed prior to the machine being used to account for any practical issues regarding the usage of the machine, any issues with the manual, and any issues regarding the risk assessment that may have been missed – such as a cable running across the floor.

In accordance with section 11 of the IRR (2017), a schedule of maintenance is to be conducted to ensure the functionality of the safety measures and therefore ensure staff safety; how often the maintenance checks should be carried out should be agreed with the manufacturer and be included in the risk assessment as a preventative measure as well as referenced in the written guidance document. The maintenance checks should be carried out by a qualified individual, mostly likely from the manufacturer themselves as the checks will involve checking the wiring, the lamps and indicators, and the alignment of tubes to the receptors (Mol 2016, 25); a record of these maintenance checks should be kept for several reasons:

- 1) to prove that the law is being followed
- 2) so that members of staff can see that the company is doing its due diligence
- 3) to prevent any minor issues with the cabinet progressing to major issues that could put the team in danger or be more costly to repair
- 4) keeping good maintenance records can make a product more desirable should the company decide to sell the machine
- 5) should the company be subject to a lawsuit a well-kept maintenance record could support the company's case
- 6) help plan for future budgets – for example, if you know from experience one part of the machine is going to need to be replaced every six months you can plan ahead and budget for the expense (Delich 2023; Gameng 2016; madhurihammad 2020)

These maintenance records should be maintained by the radiation protection supervisor (RPS). This is someone who is responsible for ensuring that the procedure outlined in the written guidance documents and any action outlined in the risk assessment is followed (UK Health Security Agency; The Ionising Radiation Regulations 2017, sec.18). These records are likely going to be completed by

the person who carries out the check, i.e. not someone in-house, but it will be a responsibility of the RPS to keep these organised and stored safely.

As mentioned earlier, a written guide explaining to team members the process of x-raying from start to finish would also be a necessity as it would set out the methodology and procedure of x-raying artefacts allowing for consistency and standardisation in the way it is done. This document would be a requirement for team members to read before being allowed to use the x-ray machine and ought to be available to the team members, both digitally and physically, for them to refer to should they need to. It should ideally be drafted prior to machine arriving so that there is no unnecessary delay in using the machine but should be reviewed and amended as necessary after the machine has been installed. The guide should follow Historic England's guidelines on x-radiography of archaeological material (2006) as it is the most comprehensive guide to x-ray technology within archaeology despite its age – should a new guide be produced the in-house manual should be updated to reflect any changes – though input from specialists should also be consulted as their different fields may have different standards; the manual is to include several sections which will be discussed here.

Firstly, the document should explain what an x-ray is and how it works. This will enable users to understand the science behind the technology and help them to understand what we're trying to achieve – it would not be necessary to go too much into detail in this section but including references and/or links to other places that could further explain this would be useful for team members who might want to know more. The next section should explain why artefacts are x-rayed. This section will explain the role of the x-ray in finds identification, conservation, and how it forms part of the archaeological record with reference to case studies and museum/archive requirements; it is important users understand why x-rays should be carried out so they know what is required from the x-ray regarding image quality, artefact placement, labelling etc. and it will be less likely to have to do the x-ray twice. Next will be explaining which artefacts are x-rayed and when – most artefacts will be x-rayed prior to assessment or as part of the post-excavation analysis stage. Most artefacts will be x-rayed as soon as they have been processed and quantified as the x-ray will aid in the assessment stage. In the case of metal finds, the x-ray can act as a record of the artefact prior to further deterioration and so the specialist who is assessing the metal finds has the x-ray available for their assessment as it will show details that may otherwise be obscured by corrosion (Historic England 2006, 4). Cremation vessels will be x-rayed prior to micro-excavation or cleaning as the x-ray can help identify any objects within the urn, such as pins or brooches, and aid in carrying out the micro-excavation (Harvig, Lynnerup and Ebsen 2012, 370, 385); x-ray also has the ability to aid in the identification of the primary forming techniques of pottery as it can detect the internal structure and orientation of inclusions that may not be seen by the naked eye (Berg 2008, 1179; Orton, Hughes; Hughes, Michael 2013, 126) so will be included as part of the post-excavation project design and carried out during the analysis stage if required. Osteologists can also benefit from x-radiography as it can aid in the identification of skeletal diseases, trauma and Harris Lines, a residual line of higher mineral density compared to the surrounding bone linked to a halt in growth in sub-adult development which can be used to investigate growth, nutrition and disease during childhood (Primeau, Jakobsen and Lynnerup 2016, 99; Scott and Hoppa 2015, 141–142; Elliott 2022); this will, again, take place after the initial assessment as part of the analysis stage as designated in the post-excavation project design.

The next stage should outline how the artefacts are x-rayed and should include information on how to get permission to use the x-ray machine and a step-by-step process on how to proceed after permission has been granted that covers both pre-assessment artefacts and analysis-stage artefacts. It might be useful to have mini-sections written by specialists about how their finds ought to be x-rayed according to any standards or best practice – for example, when x-raying dry bone, to get the best look at Harris Lines x-raying the bone both in the medial-lateral and the anterior-posterior plane is best (Scott and Hoppa 2015; Primeau, Jakobsen and Lynnerup 2016, 103). Firstly, the process of receiving permission for pre-assessment x-rays: all finds coming off site will be logged in by post-excavation processors and as such anything that would require x-raying prior to initial processing, such as urned cremations would be flagged at this stage (though one would hope this was also be flagged by the field team when they bring it back to the processing centre as it would require special attention regardless of x-ray capability). Any other finds, such as metal, ought to be dried, quantified and given a registered finds number (in line with company and archive repository guidance) prior to x-raying. When pre-assessment artefacts are at this stage then an email summary of what would need to be x-rayed (e.g. one cremation urn from context (000), or 36 iron artefacts and 12 copper artefacts from contexts (0000) and (0000)) should be sent to the RPS who can then organise a time and a date for them. A similar process will be put in place for analysis stage artefacts except the RPS should be notified by the post-excavation project manager that the analysis stage has started, and a summary of which specific artefacts should be x-rayed according to the post-excavation project design. The RPS should keep a schedule of work so they can programme the x-raying of finds for upcoming weeks when these emails are received; this schedule will allow for the RPS to track how long it takes to x-ray finds against expectation which will allow the project manager to keep track of the current budget and plan for future budgets, and additionally see the usage of the machine to evaluate if it is being used enough to justify its initial cost and ongoing costs. The schedule will also allow for the RPS to keep track of availability of qualified staff to carry out the work as well as schedule maintenance. The manual should also explain how to locate the finds to be x-rayed, how to set out the finds on the x-ray plate, how to use the safety features, and finally how to engage and disengage the x-ray beam itself. This part of the manual should include photographic examples with the machine itself in its final location so will need to be either written or edited after the installation of the cabinet. In terms of monitoring, a spreadsheet should be kept by the RPS for team members to fill out when they use the x-ray machine. The spreadsheet should include the date, x-ray numbers, exposure details, details of the items x-rayed and the initials of the person who carried out the x-ray. These details will allow the RPS to track usage of the machine against their schedule of works for budgetary reasons and also as a record of staff performance – if a specialist receives an x-ray that is over or under-exposed or doesn't show the full object it can be traced back to whoever performed that x-ray and allow for additional training or supervision to be given. Likewise, tracking users of the machine allows for their annual cumulative exposure to be tracked so that it does not go above what was expected.

In the final sections of the manual, it should outline the role of the RPS and their responsibilities as well as those of the other team members who will be using the machine, and the training required before team members are allowed to use the x-ray machine. The team members should be sent on the Radiation Awareness course where they will learn about the hazards and risks associated with radiation exposure and the steps involved to ensure this is as low as reasonably possible (ALARP) and be aware of what they need to do to keep the risk low (UK Health Security Agency 2023b). The appointed RPS should go to a more specialised course that covers the radiation awareness course, but also covers the legislation surrounding the usage and also what their role is in the eyes of law

(UK Health Security Agency 2023a). As mentioned earlier, by law the RPS is only required where the expected dosage exceeds 1mSv/y (The Ionising Radiation Regulations 2017, secs18, 19) which does not apply in this circumstance but, as the expected dosage is close to 1mSv, it is better to be safe than sorry and it would also be beneficial for staff to see that the company is doing more than what is required of them. In addition to the radiation awareness training, all staff who are expected to use the x-ray cabinet should be trained by the manufacturer (upon its initial installation) on how to use it – this should include the basics such turning it on and off, as well as explaining in detail the safety mechanisms, and practical examples so the team can see the machine in use and know what to expect. No team member should use the machine without the radiation awareness course (or in the case of the RPS their higher level RPS course), without having read and understood the risk assessment, without having familiarised themselves with the manual and local rules and without having been trained in how to use the machine itself by either the manufacturer, or if any new members are brought onto the team, by the RPS or suitably experienced team member. While still in the planning stage for the equipment introduction deciding how many team members will be required would be advisable – if only one person is fully trained then they will have to be exposed to <1mSv/y and be the only person available to use the machine, having at least two trained processors and a RPS would be better as it means that use of the machine could continue even when one trained person is on leave.

Overall, the process of introducing new equipment to a team can be a long and arduous process with many moving parts and options to consider. In this case, early discussions with the relevant team members can aid in the process being as smooth as possible as the project manager will not research options that will ultimately not reach the requirements of the specialists. Ensuring that staff are fully trained in how to use the cabinet correctly and safely can mean there are less issues later on and there is less risk to the staff and lowers the chances of having to re-take x-rays. Assigning someone to oversee the monitoring of the machine and usage thereof means that someone is taking the responsibility of staff safety and correct usage of the machine to prevent unneeded maintenance or repairs.

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