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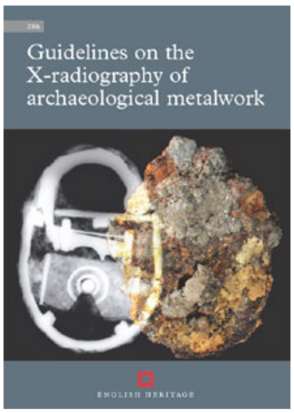
Guidelines on the X-radiography of archaeological metalwork



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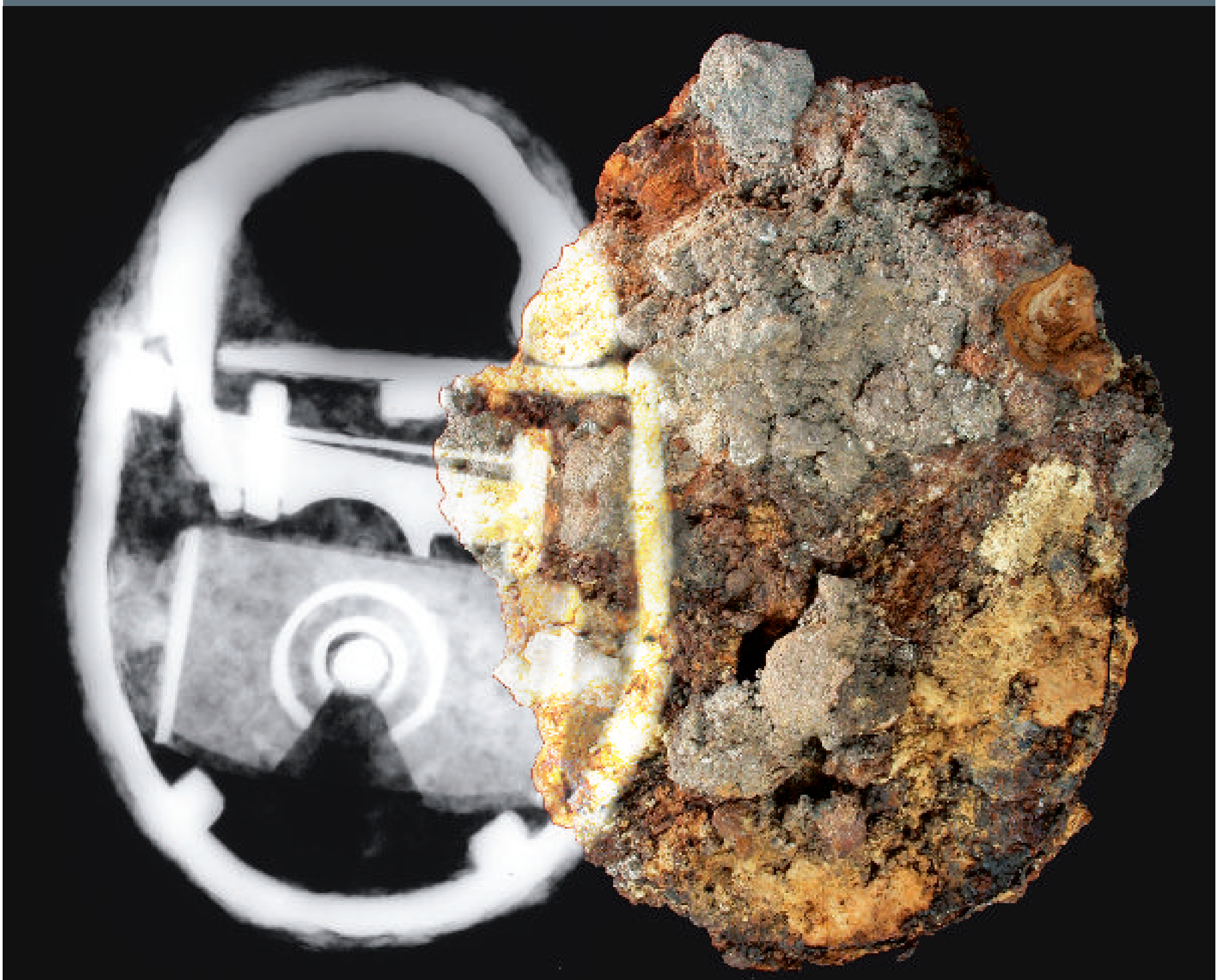
09234 6/1/06 10:11 Page 1

2006

Guidelines on the X-radiography of archaeological metalwork



ENGLISH HERITAGE

Preface

Archaeological investigations frequently yield numerous metal finds. These should be X-rayed as part of the post-excavation procedures to assist in the identification and interpretation of the finds, and thereby help understand the site. This procedure will also provide a record of the finds in the conditions in which they were recovered.

Government policy on planning issues in archaeology is stated in *Planning Policy Guidance Notes* PPG 15 (Department of the Environment 1994) and PPG 16 (Department of the Environment 1990). These documents provide guidance to local authorities and others who are required to make planning decisions and to prepare development plans. Local authority planning archaeologists are required to advise on archaeological aspects of the planning decisions and briefs, of which the X-radiography of archaeological metalwork forms a part.

These guidelines on the X-radiography of archaeological metalwork advise on good practice, including when to schedule the work and when to cost for it. They will be useful to local authority planning archaeologists when providing advice or briefs, to field project directors writing specifications, and to managers over-seeing excavation or post-excavation projects. The guidelines will also be useful to anyone directly involved with finds work, whether recording, conserving, researching or curating finds from evaluations, excavations, museum collections or the Portable Antiquities Scheme.

Within the next few years there will be advances in digital imaging and this will affect our expectations and output of any X-radiography programme. Although these guidelines give advice on good practice in the production of an 'X-ray archive' using conventional film X-radiography, they should not restrict the development of additional or different systems of archiving in the future.

These guidelines concentrate on the X-radiography of archaeological metalwork, which is one of the principal material categories to benefit from its use, providing a record of the material and assisting in a range of investigations and classification. Other archaeological materials are commonly X-rayed for a variety of reasons, such as the study of bone pathologies and analysis of soil sediments, but it is beyond the scope of this brief document to discuss these other investigations in detail, although reference to them is made where appropriate. Equally, other more specialised methods of radiography, using different techniques (such as micro-focus or stereo) or different ionizing radiations (such as gamma rays) are not covered here and so all references to radiography relate only to the use of X-rays.

Contents

1 Introduction 3

2 Why X-radiography is necessary 3

3 When to X-ray 4

4 What to X-ray 5

5 What X-radiography can show 5

6 How to make informative X-radiographs 10

7 How to view the X-radiographs 13

8 How much should it cost? . . . 13

9 Where to get help 14

1. Introduction

Aims

These guidelines provide recommendations on the minimum requirements for the X-radiographic screening of metalwork from archaeological projects. They complement and expand the advice for best practice outlined in *Management of Archaeological Projects* (English Heritage 1991), hereafter referred to as 'MAP2'. The guidelines offer advice on what to X-ray, when X-radiography should be undertaken, the standard of X-radiograph necessary, and how best this can be achieved. They do not provide practical instructions on X-radiography or describe the basic principles involved. These topics are covered elsewhere (eg Lang and Middleton 2005). They will be of use to those who commission, manage or monitor post-excavation projects involving the recording and analysis of metal finds, and to those who produce and use radiographs in the course of such work.

Why the guidelines came about

The need for guidelines on the X-radiography of archaeological metalwork was recognised at a meeting at the Museum of London in February 2003 ('All may be revealed – X-radiography and archaeological artefacts') organised jointly by the Archaeology Group of the Institute of Conservation, the Finds Research Group AD 700–1700, and the Roman Finds Group. The meeting was held to stress to those commissioning, managing and undertaking archaeological projects the necessity for high-quality X-radiography to enable the satisfactory assessment, recording, analysis and conservation of archaeological material. At the conclusion of the meeting it was agreed that guidance on the basic standards was required.

2. Why X-radiography is necessary

X-radiography is an invaluable investigative technique that is non-destructive, quick and cost effective. It enables the form and structure of an object obscured beneath corrosion layers and burial accretions to be viewed without any physical intervention to that object (eg Figs 1 and 2). In some circumstances, such as when an iron object is heavily or even completely mineralised, an X-radiograph can provide information that cannot be gained by any other method. Technological details can be revealed without the need for interventions. In addition, the X-radiograph itself provides a long-term visual record of inherently unstable and potentially deteriorating artefacts. While much can be done to slow down the deterioration processes of metal artefacts following their removal from burial, X-radiography should be initiated as soon after excavation as is practicable. A good quality X-radiograph may provide the information necessary to identify, classify, date and illustrate an object that has subsequently disintegrated beyond reconstruction.

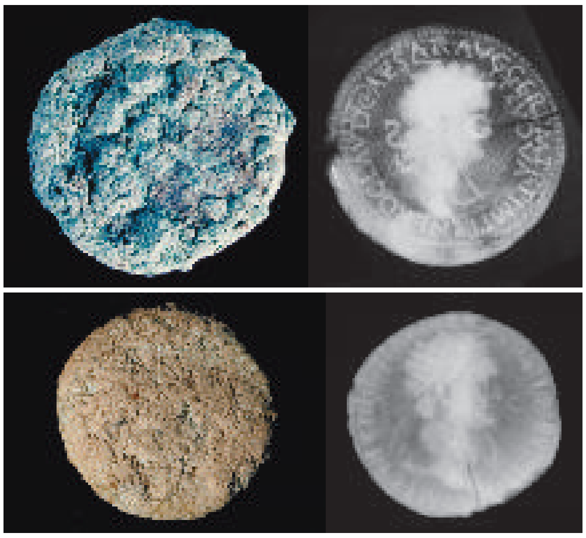


Fig 1 Coins can sometimes be dated from their X-radiographs. The two Roman coins, shown as excavated and their X-radiographs, are (upper) a sestertius of Nero dated AD 54–68 and (lower) a dupondius of Domitian dated AD 95–6.

X-radiographs of metalwork are an essential component of the site archive (English Heritage 1991, 30, A3.1.1) and, where necessary, the research archive (English Heritage 1991, 37, A6.1.1) and are a requirement of the deposition of those archives. The guidance now in place from PPG15, PPG16 and MAP2, makes it clear that an X-radiographic archive is an integral part of the transfer of an assemblage of metalwork when the project archive is finally deposited.

The benefits of X-radiography may be summarised as follows:

- visual record of shape, technology and condition
- aid to identification
- non-interventive
- non-destructive
- cost-effective
- long-term record of deteriorating objects

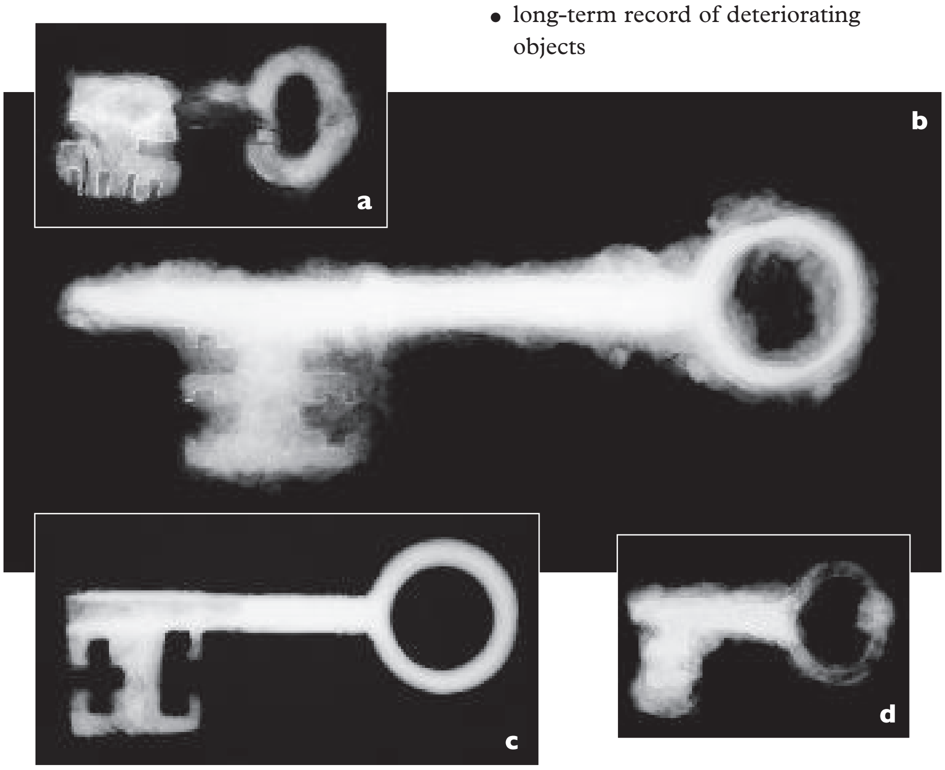


Fig 2 Good quality X-radiography reveals features of the four keys illustrated (2a–d) that are obscured by corrosion and not visible even under magnification. Three of the four (2a, 2b, 2d) are plated, two (2c, 2d) have decorative mouldings at the neck, one (2c) being finely grooved. The nature of the key bit is clarified on three of the examples. 2a has multiple clefts, 2d has opposing channelled clefts. 2b is a door key as, having a symmetrical bit, it could be used from either side of the lock. It has a solid stem projecting beyond the end of the bit and a collar above. The stem of 2c is hollow and the piped stem fitted over a locating pin in the lock. Length of keys: 2a, 65mm; 2b, 175mm; 2c, 98mm; 2d, 58mm.

3. When to X-ray

It is important to X-ray metal objects as soon as possible following any archaeological investigation in order to provide an archival record of the items and their present condition as, under certain circumstances, deterioration may quickly set in. The early identification and dating of the finds from a range of interventions, including evaluations, may contribute to the interpretation of the site and thus inform subsequent action. (Table 1)

Financial provision for X-radiography should be made at the **planning stage** of a project, when the costed project design is compiled (English Heritage 1991; Institute of Field Archaeologists 2001). By this stage in the project, the core team members will have contributed to the project design and the need for X-radiography should have been recognised and an appropriate organisation contacted.

Table 1 X-Radiography: Guidance for Project Planning

MAP2 phase	*Actions and outcomes*
1 Project Planning	• Project Manager and Contractor undertaking X-radiography identify the likely requirements (this will depend on factors such as site type, size of excavation, specific needs of receiving organisation, etc). In order to inform project budgeting, establish factors such as likely volume of material for X-radiography, possibility of large items such as soil blocks, and if large-scale facilities will be needed. • Estimate costs for X-radiography based on above • Identify core team members and principal contacts • Liaise over proposed timetabling • Prepare costed project design
2 Fieldwork	• Decide materials and categories for X-radiography • Compile list of finds for X-radiography • Transfer material and list to contractor (eg laboratory) undertaking the work. This should occur during, or at the end of, the evaluation or excavation. • Confirm costs based on assemblage received • Produce initial X-radiographs in archival quality envelopes, and supply X-ray data to allow for completion of the basic record* before the site archive is completed • If no formal assessment is to take place, transfer the site archive**
3 Assessment of Potential for Analysis	• Results of X-radiography to inform assessments and contributions towards the finds and conservation assessment reports • Establish further X-radiography requirements through liaison of appropriate specialists and core team members to inform updated project design and additional project costs • Update records accordingly • If review of assessment report shows that an analysis phase is not required, transfer the site archive**
4 Analysis & Report Preparation	• Produce additional X-radiographs as agreed during the assessment, or for other requirements identified during analysis • Update records accordingly • Transfer the site archive**
5 Dissemination	• Site publication • Advocacy of project through other agreed media

Notes:
*The *basic record* of an object or group of objects forms part of the site archive, as specified by the Roman Finds Group and Finds Research Group AD 700 – 1700 (1993).

**Project Manager transfers the site archive (finds, X-radiographs and records) to the project archive for deposition with agreed receiving organisation. The transfer of the archive can occur at three different stages depending on the project type and complexity: after the fieldwork stage (English Heritage, 1991, 13, 5.6), after a review of the assessment (English Heritage, 1991, 18, 6.15), or after analysis and report preparation (English Heritage, 1991, 23, 8.2).

The initial X-radiography should be implemented at the **fieldwork phase** of a project so that the site archive, the product of the fieldwork, can be completed. Decisions should be made between the appropriate core team members and any other relevant specialists about what components of the finds assemblage will be X-rayed (*see* Section 4).

A basic record of a metal object – as specified in Roman Finds Group and Finds Research Group AD 700–1700 (1993, 3) – cannot be undertaken without consulting a good quality X-radiograph. When submitting metalwork for radiography, data about the objects to be X-rayed should be supplied with them, preferably in an electronic form so that the radiograph numbers can be added digitally. The data should include the site name and the site identifying number (if allocated), context, unique identifying object number (if allocated), material type where known, box number (if allocated), and any relevant associations or other information (available at that time).

The metalwork component of the archive cannot be **assessed for potential for analysis** without reference to X-radiographs. Provision of high quality X-radiographs will provide sufficient information for the majority of the assemblage to be recorded and studied as necessary for archive and analysis. These X-radiographs will normally include multiple exposures of many types of artefacts in order to show the full variation in morphology (*see* Section 6).

Additional X-radiography of selected items may be required during the **analysis phase** of the project, for example to clarify certain features or to investigate particular aspects of an assemblage. This requirement will usually be identified during assessment and will be costed with the analysis phase. Recommendations for further examination and analysis should be made following consultation between the finds specialists, conservator, excavator and any other relevant contributors.

4. What to X-ray

The majority of metal artefacts and metal composite artefacts should be X-rayed. These will include ferrous and non-ferrous metals and alloys, including coins.

There are, however, several categories of metal finds that might *not* necessarily merit radiography, depending on the nature of the archaeological project. Examples of these include:

- lead alloys and heavily-leaded copper alloys, where these will not yield informative X-radiographs (for example, thick and chunky items such as melted roof lead, and leaded copper alloy cast handles)
- some copper alloy finds from waterfront sites, where these are free of accretions and X-radiography will not reveal additional technological information (for example some sheet metal and wire)
- thick pieces of metal, where these will not yield informative X-radiographs using the facilities available (for example industrial artefacts such as very large bars and blocks)
- items that are obviously modern and easily identifiable, such as many finds from plough soil, and that have not yet been critically sorted for discard (for example, parts of agricultural machinery, gun cartridges and bullets, modern household items)
- unstratified finds where these are clearly of no archaeological significance (English Heritage 1991, 33, A4.3)
- very large assemblages of clearly identifiable nails are sometimes sampled for X-radiography where there is no academic value in examining them all
- large architectural and structural items, such as components from post-medieval industrial complexes

Decisions on materials to be excluded from the X-radiography programme should be made between the core team members of the project, and it may be relevant to record the reasons in the site archive.

In the assessment report it is normal to record the proportion or number of finds X-rayed as a statement of the means of collecting the data (English Heritage 1991, 32, A4.1.2), as well as stating the additional X-radiography requirements within the statement of potential.

Where large or substantial artefacts merit X-radiography and suitable archaeological facilities are not readily available, large-scale industrial facilities should be sought.

5. What X-radiography can show

Object identification

Accretions can be so dense that the original shape of the object is obscured. This happens particularly with ferrous artefacts, which are more susceptible to this extensive form of deterioration

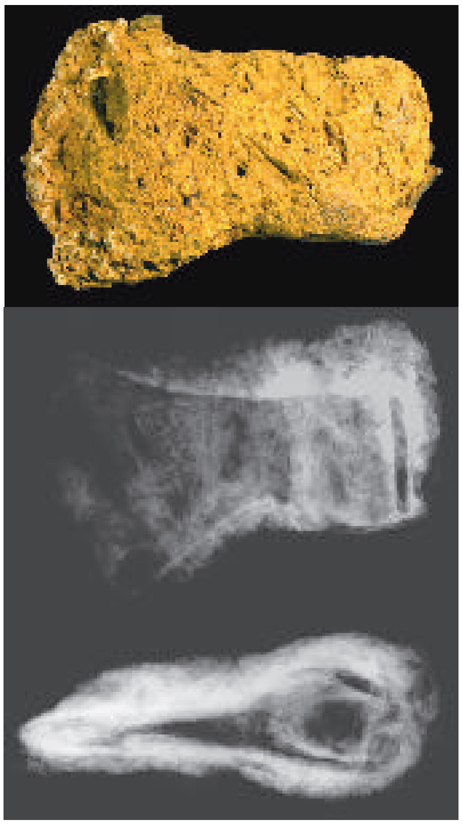


Fig 3 Medieval iron axe-head. The much accreted block masks the identity of the axe-head but is clearly visible in the X-radiographs taken in side and plan views. There is no metal surviving in the axe-head, which is now largely voided and is more transparent to X-rays than the surrounding accretions. Length of axe-head: 168mm. Exposure: 3mA, 110kV, 300s, 0.47m FFD, Kodak Industrex MX.

(Fig 3). A less-encrusted item might be readily identifiable when complete but subject to mis-identification if broken and only partially surviving. Implements for writing, leatherworking and textile-processing may be indistinguishable from broken nails when corroded, for example. Similarly, coins with surface detail obscured by accretion can be identified by X-radiography in some instances (*see* Fig 1). When this cannot be done, the radiograph informs decisions regarding the prioritising of subsequent action (eg Brickstock 2004, 24).

Other identifications may depend on more subtle variations in the radiographs, which rely on rigorous techniques of both image capture and viewing in order to draw out the information. An example of such evidence is the survival of organic material through mineral replacement, for example the presence of organic sheaths and scabbards associated with swords, daggers and knives (Fig 4). This kind of pseudomorphic evidence can be extremely faithful (to the extent of, for example, indicating the positions of stitch holes in leather), but can also be easily overlooked if X-raying technique is poor.

Particularly fragile, complex finds or closely-associated groups of objects are often lifted in a block of the surrounding soil to enable careful excavation back at the laboratory. X-radiography is invaluable in clarifying and locating the contents of a soil block when laboratory excavation is undertaken (eg Watson and Edwards 1990, 98, pl 1). Additional X-radiographs, taken after excavation of the soil blocks, are normally required to clarify detail of the metal artefacts. Similarly, soil monoliths can be X-rayed to show where metal ions have concentrated or to show the effects of rootlets or other features

Fig 4 Early medieval knife with horn handle and leather sheath. The junction of the handle with the blade is clearly visible in the X-radiograph owing to iron mineralization of the different organic layers. Part of the handle is visible in the radiograph where the horn has been preserved by mineralisation on the tang. The sheath shows as an irregular and discontinuous line around the blade and also where it extends over part of the handle. Length: 170mm.

09234 6/1/06 10:11 Page 6

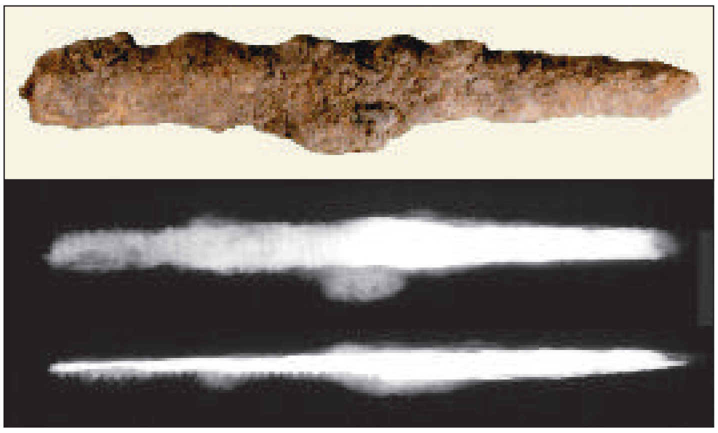


Fig 5 (above) Iron Age iron file, as excavated and X-rayed in side and plan view showing that the cuts which form the teeth are on one face only and are raked (length 91mm).

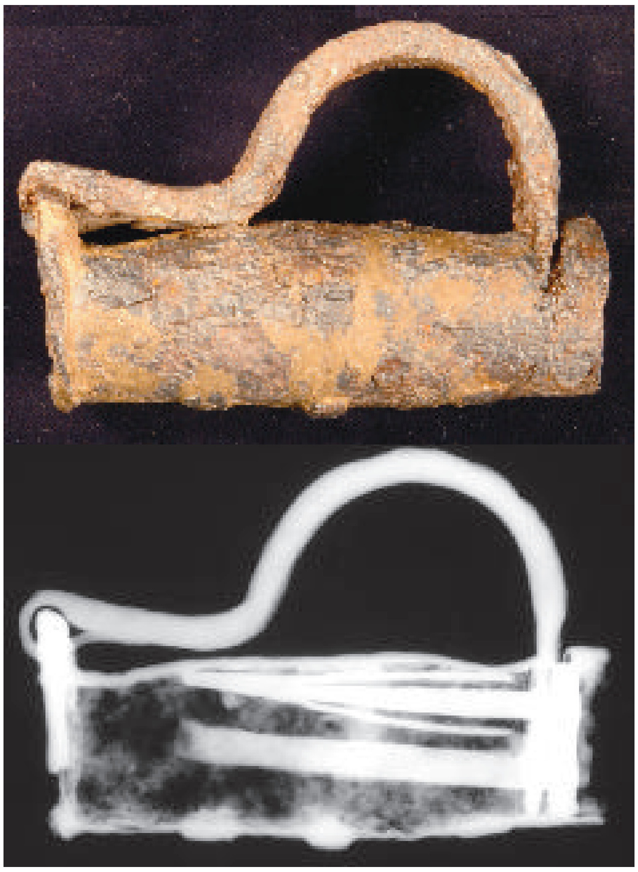


Fig 6 (above) Medieval barrel padlock: the mechanism is revealed in the X-radiograph but is not otherwise visible, even after conservation. Length: 95mm. Exposure: 3mA, 110kV, 240s, 0.47m FFD, Kodak Industrex MX.

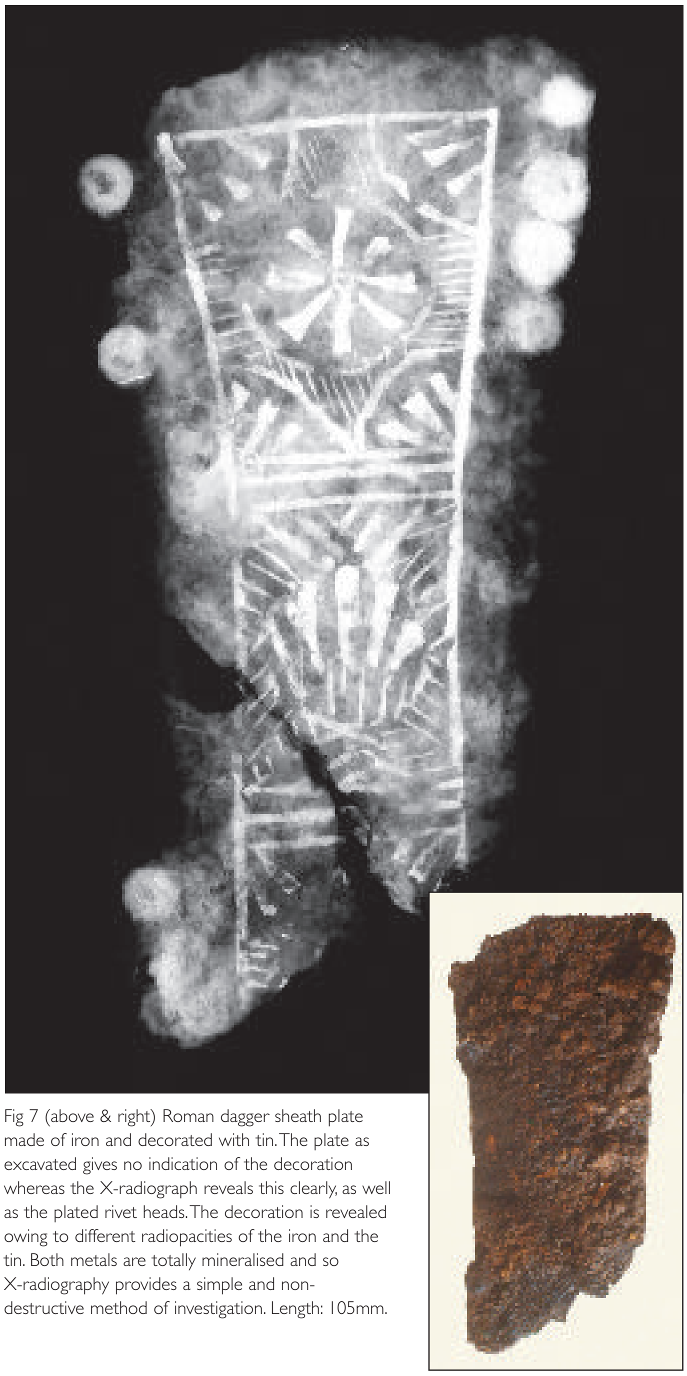


Fig 7 (above & right) Roman dagger sheath plate made of iron and decorated with tin. The plate as excavated gives no indication of the decoration whereas the X-radiograph reveals this clearly, as well as the plated rivet heads. The decoration is revealed owing to different radiopacities of the iron and the tin. Both metals are totally mineralised and so X-radiography provides a simple and non-destructive method of investigation. Length: 105mm.

Fig 8 (below) Early medieval spearhead. The X-radiograph shows the form and level of deterioration and the detail (left) reveals an inlaid maker's mark formed of a metal with greater radiopacity than the ferrous metal.

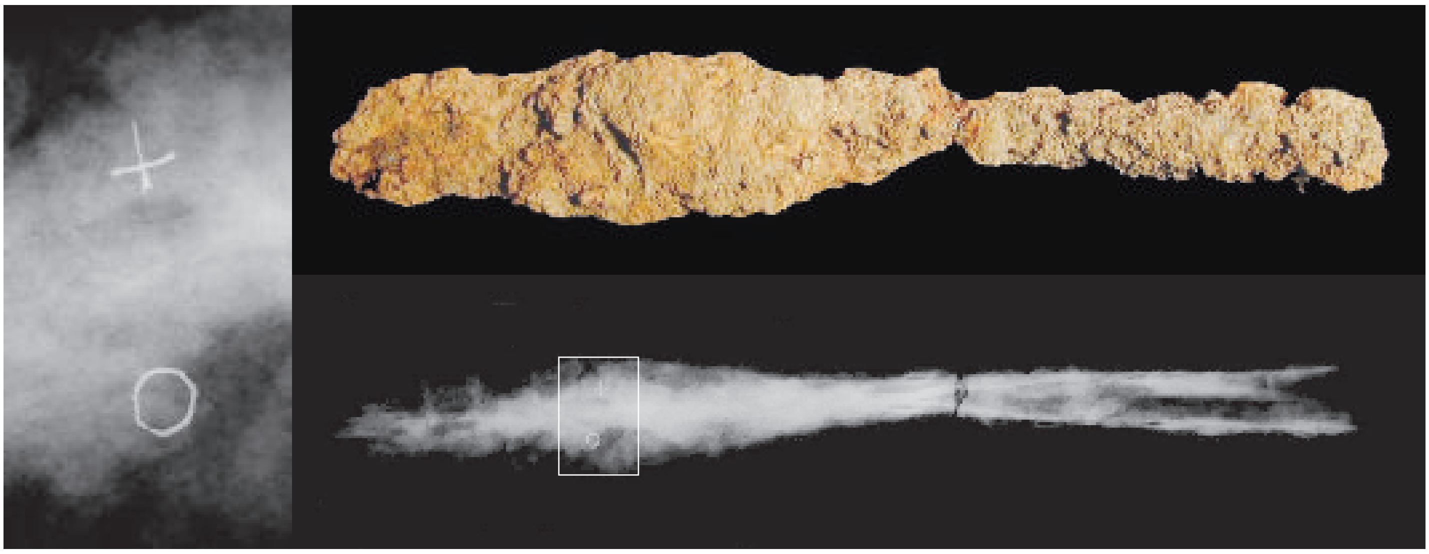


Fig 9 (left) Roman cross-bow brooch made of leaded bronze and decorated with openwork on the foot. Gilding is visible as a brighter line to the metal where it survives through protection by the relief. The radiograph also shows that the onion-domed heads are hollow, one of which is missing and one is broken. The stem is hollow to take the pin.

(eg Canti 2003, fig 40; English Heritage 2004, 20). X-radiography cannot alone identify the composition of artefacts although it can often provide clues to the nature of the material or materials based on the micromorphology visible, especially for organic materials such as bone and wood.

Iron corrodes in a distinctive manner that is normally recognisable on X-radiographs but identification of non-ferrous metals in particular relies on analytical techniques such as X-ray fluorescence (eg Bayley *et al* 2001, 25).

Form and structure

X-rays will show size, shape and details of construction of the items under examination that will aid object identification as well as contribute to their characterisation, technical description, classification and dating. Examples range from details of the cuts and ridges that form the 'teeth' seen on a file (Fig 5), to the clarification of a complex item such as a barrel padlock mechanism (Fig 6).

Surface features

X-radiography can elucidate decorative surface features – such as inlay, a wash of metal, or fields of enamel or niello – because the different chemical composition of the material comprising the object and that forming its surface decoration is revealed. Thus non-ferrous metal can be seen decorating an iron dagger sheath (Fig 7) and an inset maker's mark is visible on a spearhead blade (Fig 8). Incised lines, tool marks and maker's stamps, show due to differences in metal thickness (*see* Figs 5, 13 and 16).

Non-ferrous metal coatings, such as gold on copper (Fig 9) or tin on iron (*see* Figs 2 and 7), will give a distinctive sharpness to the surface of the object in the image due to the relatively higher density of the coating material. Similarly, the use of lead-tin solders and copper-based brazing materials for joints will be evident.

Fig 10 (below) Early medieval knife with a weld line in the blade where the steel edge was joined to the iron back. Length: 100mm.

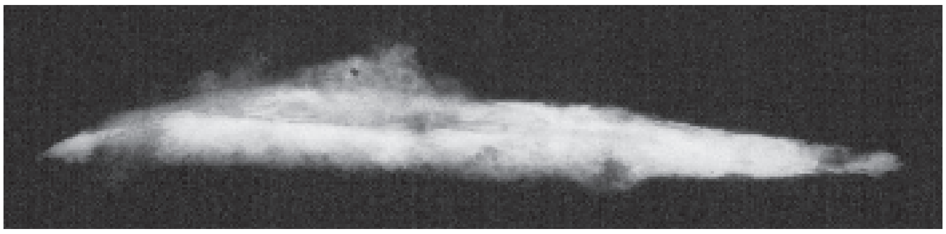


Fig 11 (below) Early medieval knife with pattern-welding in the back of the blade. Length: 178mm. Exposure: 3mA, 110kV, 60s, 0.45m FFD, Kodak Industrex MX.

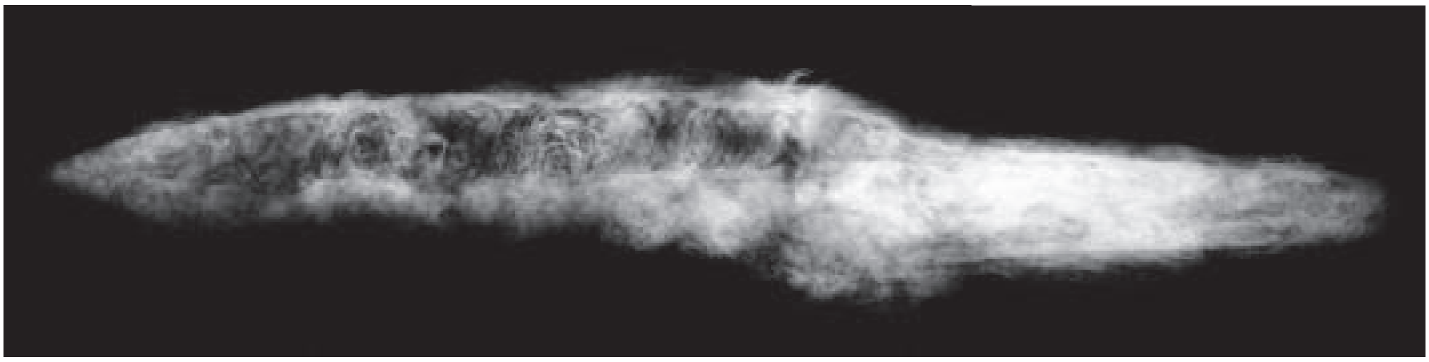


Fig 12 Medieval copper alloy spearhead. The X-radiograph shows complex structure within the blade, which is not visible on the object after conservation. Exposure: 3mA, 110kV, 210s, 0.47m FFD, Kodak Industrex MX.

09234 6/1/06 10:11 Page 8

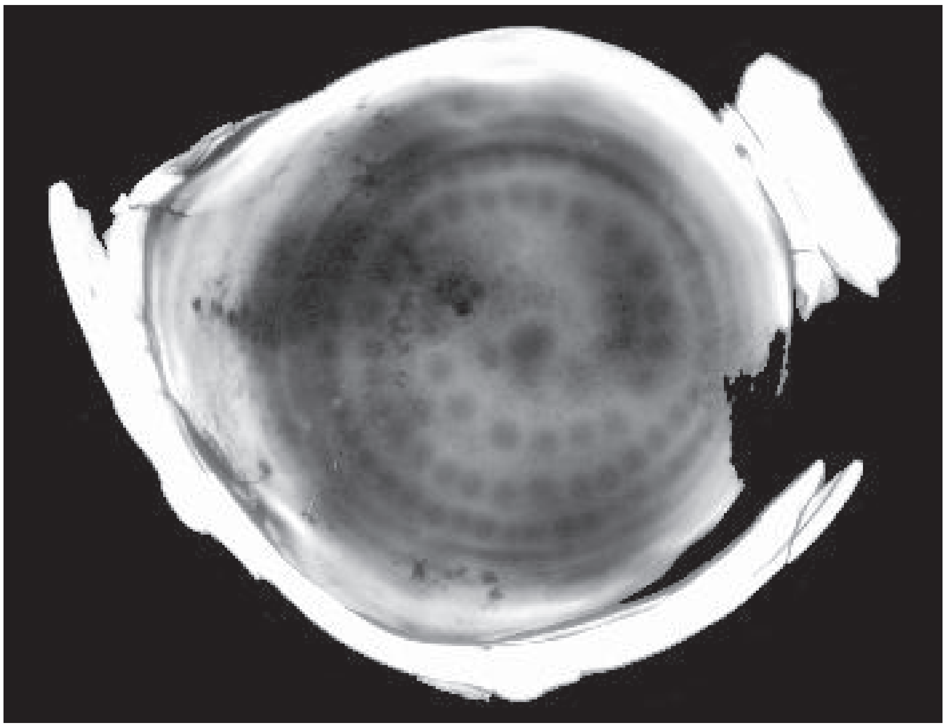
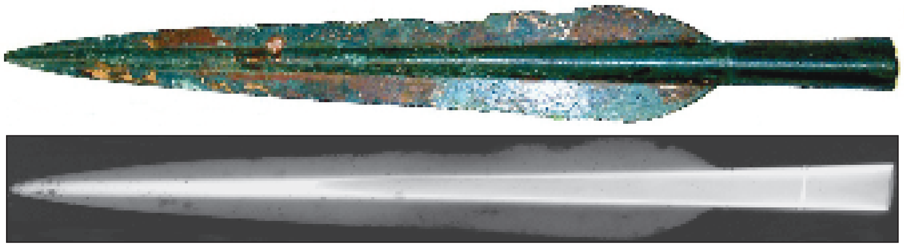


Fig 13 Hammer marks visible in the X-radiograph of a medieval copper alloy bowl show that the vessel was raised from sheet metal. Dimension across: 108mm. Exposure: 3mA, 110kV, 120s, 0.47m FFD, Kodak Industrex MX.



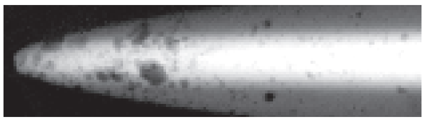


Fig 14 Late Bronze Age spearhead. Porosity in the tip of the blade, visible as dark areas due to voids in the metal, indicates that it was made by filling the mould with hot metal from the blade tip. Exposure: 10mA, 230kV, 30s.

Technology

X-radiography can provide a range of technological information about the manufacture of an object, from details of the microstructure of the metals and alloys employed, whether it was made from sheet metal, wrought or cast, through to details of the construction of complex artefacts.

X-radiography shows the structure of a blade, for example, that might vary from a simple weld line joining the back and the cutting edge (Fig 10), to complex pattern welding (Fig 11) or other structural detail (Fig 12) seen in prestigious edged blades. This information not only aids description, identification and dating but also assists subsequent examination, such as microstructural analysis, informing the choice of sample area through the consideration of condition and structure.

X-radiography may reveal tool marks that can indicate if a non-ferrous metal vessel was made by hammering (Fig 13) or turned or spun on a lathe. It can also provide details of manufacture of a cast metal object and its quality, as revealed by the extent of porosity visible (Fig 14). The positions of ingates, for filling the mould, may be seen. Chaplets that held the core in place may survive or, if destroyed, may be detectable as voids caused by differential corrosion. Evidence for the repair of items or the recycling of materials, seen when features from an earlier object is revealed, may also be

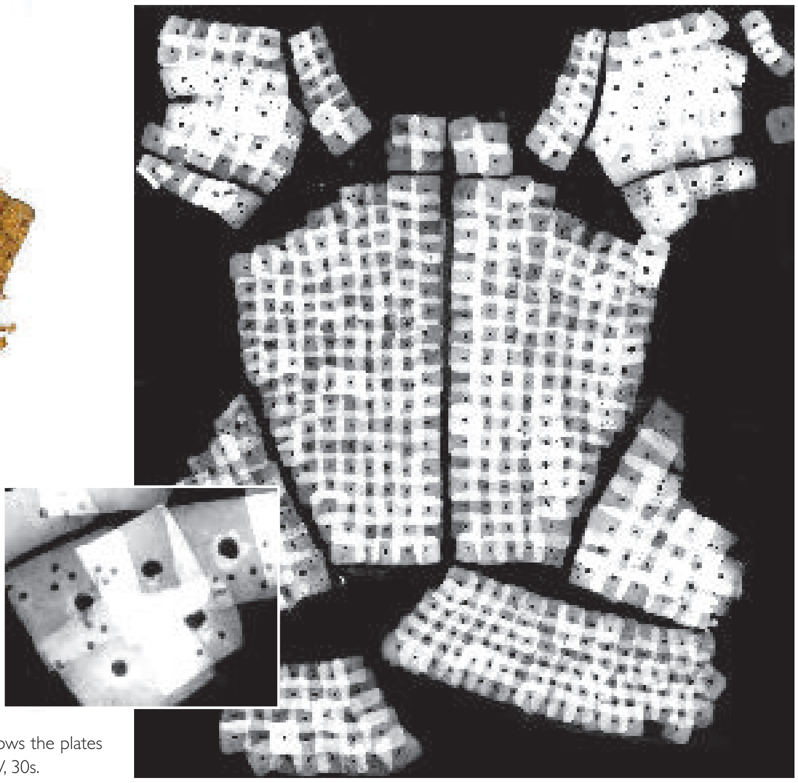


Fig 15 Late 16th-century 'Jack of Plates' made from recycled iron sheet. The detail shows the plates with distinctive rivet holes of the late 15th-century brigandine. Exposure: 5mA, 130kV, 30s.

09234 6/1/06 10:11 Page 9

Fig 16 Early medieval shield boss as excavated (upper). The X-radiograph reveals hammer marks aligned around the apex from forging the iron boss to shape (middle). The studs are made from silver alloy and thus show in the radiograph due to differences in metal composition. These were revealed during conservation (lower).

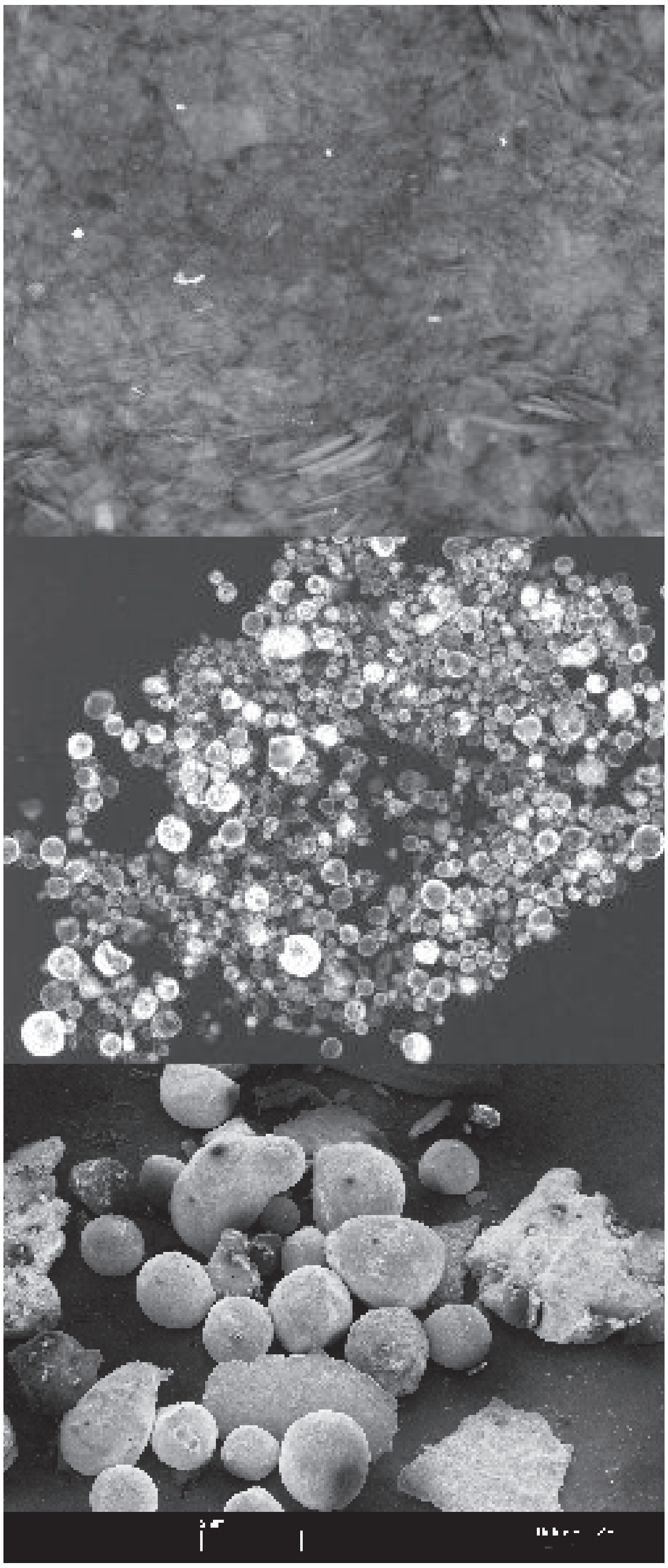


Fig 17 (bottom) Soil samples containing ferrous hammerscale from a blacksmith's hearth, comprising flakes and spheres visible in the scanning electron micrograph. (top and middle) X-radiographs: top shows flake hammerscale, comprising individual flakes that show as bright lines if they are vertical to the X-ray beam on exposure; middle shows spherical scale, comprising hollow and part hollow spheres. Hammerscale can also be found within the accretions surrounding an artefact.

visible in the X-radiograph (Fig 15). Complex artefacts such as shield bosses may reveal details of manufacture and construction, including the use of different metals (Fig 16).

Evidence of manufacturing processes, such as ferrous hammerscale (Fig 17) and non-ferrous metal casting waste (Fig 18), is sometimes found within the soil or corrosion layers associated with artefacts. Lead casting waste, if oxidised, can be mistaken for mortar in the soil unless it is X-rayed. Other evidence can be found by X-raying soil samples selected for specific

09234 6/1/06 10:12 Page 10

Fig 18 Medieval nail. The X-radiograph shows non-ferrous metal casting waste trapped within the corrosion layers. Length: 65mm.

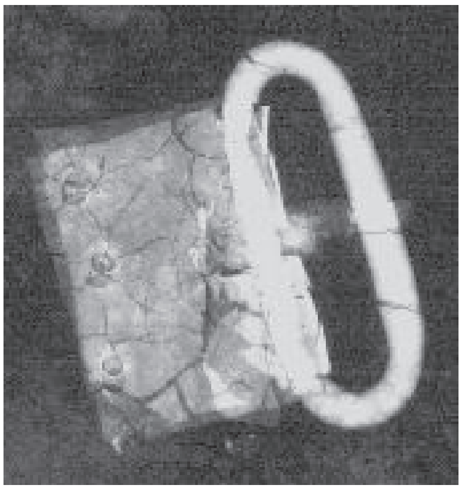


Fig 19 Bronze buckle from an early medieval grave. The buckle is fissured and very fragile and now comprises mostly tin oxide and copper carbonate. This is a consequence of decuprification of the bronze in the acid burial environment. Length: 21mm.

Fig 20 Roman nail, completely corroded., The X-radiograph reveals a void within the accreted block.

investigation, such as those from around a smithing hearth (eg Bayley *et al.* 2001, 14; Starley 1995), or by X-raying certain types of manufacturing implements, such as ceramic crucibles for evidence of non-ferrous waste metal.

Condition

The archaeological interpretation of finds can depend on features of condition, such as completeness before burial, or subsequent damage. Knowledge of the condition of an artefact, in terms of the presence of fissures (Fig 19), fractures or the extent of mineralisation (Fig 20), can inform decisions on subsequent examination and the conservation programme, particularly when finds are very fragile.

6. How to make informative X-radiographs

Film or digital?

At the time of writing (2005), the standard image capture method in archaeology is the production of conventional film radiographs. In part this is because of the much lower cost associated with setting up such a system. At present, the image quality of medium-priced digital systems is not sufficiently good for archaeological applications other than for the basic scanning of soil blocks. Digital systems are improving in quality and may in time become the standard technique for image capture in relation to archaeological archives (*see* Richards and Robinson 2000). The guidance offered in sections 1–5 will still apply.

Digitisation of film radiographs is sometimes employed as a means of study and dissemination between finds workers, although the initial X-radiographs will remain the prime source of data and archive, and the quality of these original X-radiographs is paramount. Image enhancement is also employed, but its use should be made known to the finds researcher. These topics are covered in more detail elsewhere (Lang and Middleton 2005; O'Connor and Maher 2001; O'Connor *et al* 2002).

Film radiographs

Film radiography is essentially the same as the process used for conventional medical X-radiography in which a two-dimensional negative image is captured on photosensitive film (Fig 21).

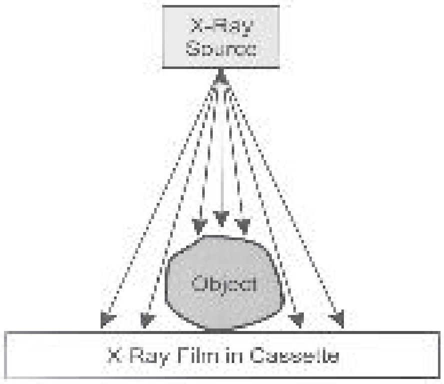


Fig 21 Figure showing the basic layout during exposure.

The image size is approximately 1:1 if the exposure is made with the artefact in close contact with the film, although dimensional distortions can arise for a number of reasons (*see below*).

To achieve the maximum information and quality in X-radiographs requires some knowledge of the nature of the assemblage and a rigorous methodology. The first will enable the best orientations and exposures to be selected, while the latter will facilitate good quality images and a clear understanding of the relationship of the image to the original artefacts. Operator skill and experience plays a crucial part in the process.

For the basic principles and methodology of X-radiography, the reader should refer to standard texts, in particular Lang and Middleton (2005). Detailed technical information on equipment, materials and methodology is available in publications on industrial radiography (eg Kodak 1985; 1987; Quinn and Sigl 1980; Halmshaw 1986) and in manufacturer's technical data on specific products such as films, processing equipment and chemicals (often available through their web pages).

The sections below assume basic knowledge of the X-radiography process and offer guidance on how to achieve clear and unambiguous images, suitable for the purposes of identification, analysis and illustration, and to provide the archival record.

Health and safety legislation

There are several statutory (legal) health and safety requirements for any laboratory using ionising radiations including X-rays, and also for using certain related materials and processes.

- The Ionising Radiations Regulations 1999
- The Control of Substances Hazardous to Health Regulations 2002

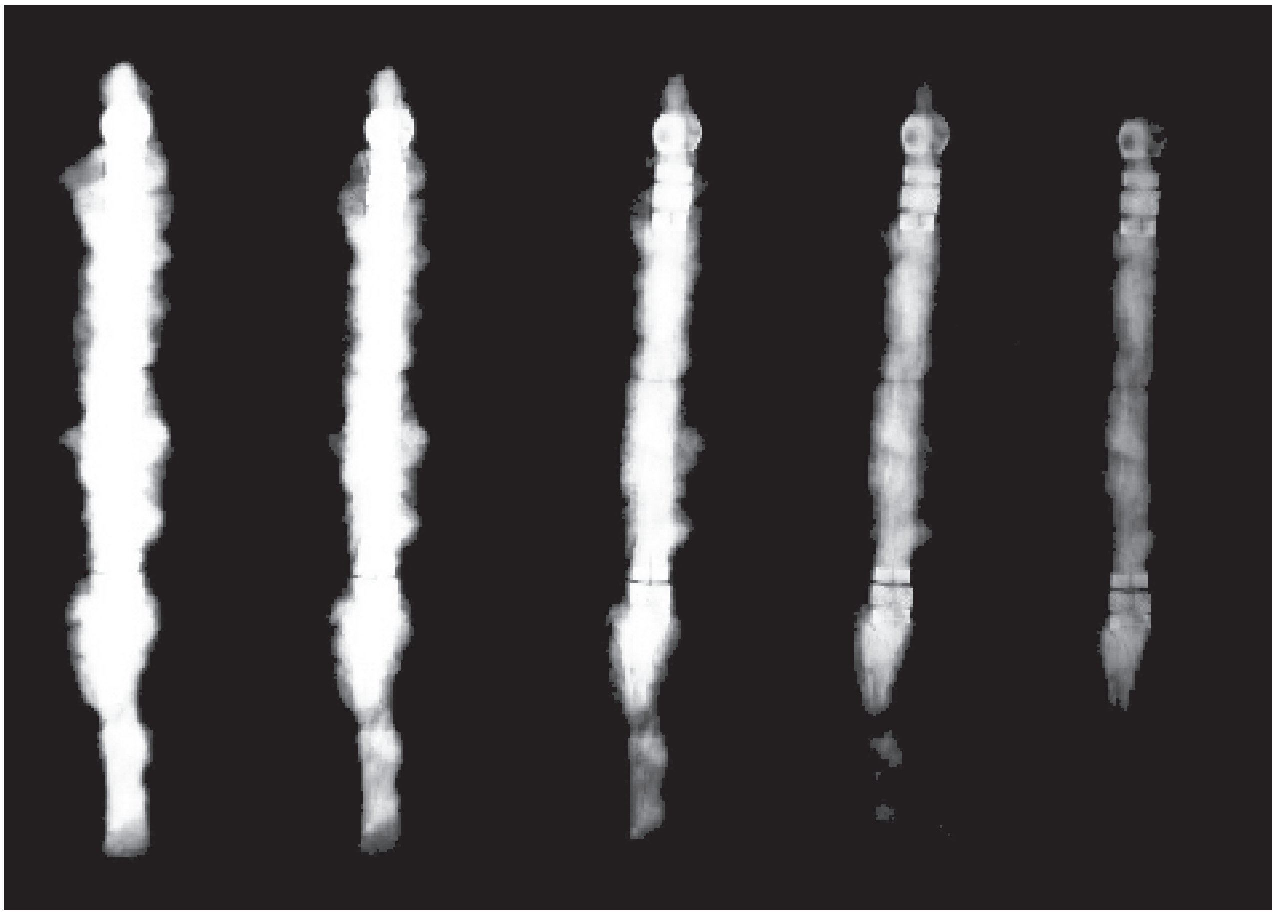


Fig 22 Roman iron stylus decorated with brass and silver (length: 108mm). The five exposures of the same stylus were made by increasing the X-ray energy from left to right. *Left*, the outline of the corroded layers is visible as well as the tip and the eraser, but very little detail of the decoration can be seen. *Right*, the higher exposures reveal detail of the inlay, although this is to the detriment of the outline of the whole implement, which appears to be shorter as the tip and eraser become over exposed and merge into the background. Exposures, left to right: 70kV to 110kV in 10kV steps, all at 3mA, 60s.

- The Control of Lead at Work Regulations 2002
- http://www.hse.gov.uk/

The process of X-raying archaeological material is usually completed within a conservation laboratory, a museum or university research facility. Staff undertaking this work must comply with the legislation.

What affects the image?

The image produced through X-radiography depends on the interaction of the X-rays with the materials under examination, which is a function of the artefacts, the equipment and the exposure. The image quality is also affected by film development conditions. Details in the X-radiographic image might be missed if the viewing conditions are inadequate.

The artefacts

Certain characteristics of the artefacts will affect the image produced during X-radiography. These are:

- thickness
- density
- chemical nature of the artefact (and associated accretions)
- geometry and orientation in relationship to the X-ray film

The equipment

The basic X-ray equipment, whether a bench-top cabinet unit or a larger-scale industrial unit, will have several variables in terms of exposure:

- intensity, or quantity of the X-rays – controlled by the current in milliamperes (mA). This might not be a variable for some cabinet units.
- energy, or quality of the X-rays – controlled by the kilovoltage (kV)
- duration, or length of time of the exposure

Film type

The preferred type of X-ray film to use for archaeological artefacts is very fine grain industrial film. This has film emulsion on both sides and has high contrast and high definition.

Film holders

X-ray film is light sensitive and is placed in suitable light-tight holders (cassettes) while being exposed to X-rays. Otherwise it is only handled in the darkroom under the illumination of an appropriate safelight until fully processed. The film is normally used within rigid cassettes, in which lead intensifying screens are held in close contact with the film. These screens are employed with industrial type film in order to minimize the effects of scattered radiation, thus improving image contrast and increasing the exposure latitude. At voltages above 120kV, the screens will also serve to intensify the image. At lower voltages there are benefits in terms of reduction in scattered longer wavelength radiation and improved clarity and sharpness of the image. Pre-packed film with integral lead screens is also available, which in roll form is particularly useful for long artefacts, such as swords.

Occasionally it is useful to employ a flexible cassette, for example to wrap around a bulky object such as a vessel. In these cases, the pre-packed film mentioned above is useful, or the film can be sealed within light-tight envelopes. Whichever system is employed, every effort should be made to incorporate lead screens within the cassette or envelope.

The exposure

Multiple exposures

It is often useful to make several exposures of each artefact, either to adjust the orientation of the object in the beam, or to present a suite of images to suit differentially degraded components or areas of interest. For example, an iron stylus decorated with non-ferrous metals can be X-rayed to show different aspects of its construction (Fig 22).

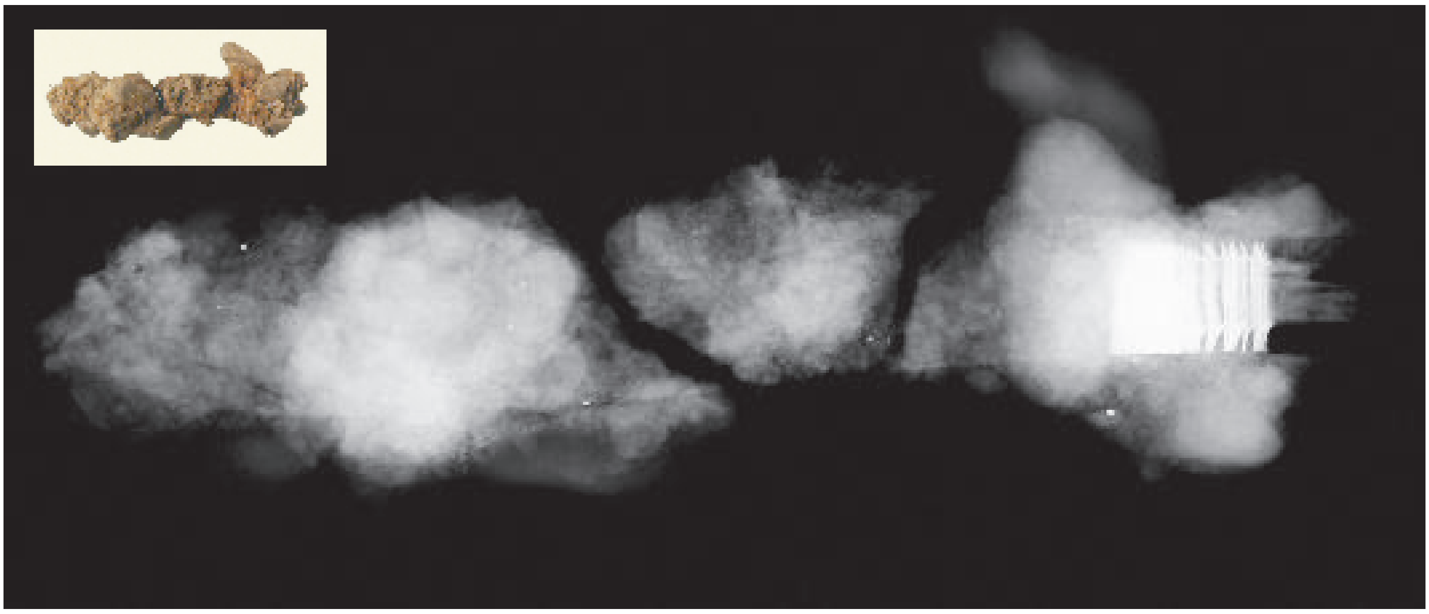


Fig 23 Encrusted iron knife, 12th century. The X-radiograph reveals non-ferrous metal components on the bolster and tang, subsequently shown to comprise a bronze bolster at the junction of the blade and tang, and numerous close-set brass plates on the tang. The latter were probably separated by thin horn plates, which no longer survive (Ottaway 2003, 272).

Another example, a medieval knife – which will have a blade of wedge section, possibly corroded away at the cutting edge – will benefit from one exposure to match the back of the blade and another to match the cutting edge. If the handle is complex, such as a decorated scale tang handle, a third exposure at 90 degrees to the other two exposures but in the plane of the blade might be required, to reveal the lengths of the rivets or other constructional detail. There are a number of potential constructional and technological details that may be present on knives, including makers' marks, microstructural detail such as welded-on edges or pattern-welding (Fig 11), complex decorated handles (Fig 23), and traces of organic sheaths and handles preserved as ferrous pseudomorphs where the iron corrosion products have concentrated (Fig 4).

Generally, multiple incremental exposures, varying either exposure duration or energy of the X-ray beam, will provide a series of images of the same object to accurately record the variation in its morphology. Similarly, precise and specific object rotations (usually through 90°) are equally important (Figs 3 and 5). Suitable props can be made of radiolucent materials (transparent to X-rays) such as polyethylene foam cut into wedges or other shapes.

Masking off

The easiest way to provide multiple exposures is to mask off the film in its cassette during exposure, allowing all the exposures relating to a single item to be placed on the same X-radiograph. This is readily achieved with square-cut sheets of roofing lead, placed to almost butt up to the line of the previous sheet. With care, numerous masking off operations can be performed on one film without the final developed radiograph showing any white cut-off lines, which occur if the lead sheeting is overlapped (ie where film is not exposed). However, image cut-off can result from inexact masking, overlapping the lead sheet on an area of previously exposed object. The health risks associated with handling lead dictate that the appropriate protective equipment be worn (The Control of Lead at Work Regulations 2002), or the lead sheet can be coated or covered.

Other factors to consider

1 To assist the division of finds to different specialists, as well as to produce a more useful archival record, large assemblages can be X-rayed by material or artefact type – for example the coins can be separate from the other copper alloy artefacts.

2 Some groups of finds may comprise numerous very small components or dislodged fragments. These will probably all need to be X-rayed, and often at different exposure values for the different components. This can lead to complex imaging but the additional time and patience can be justified. Similarly, fragmentary artefacts (with recent fractures) may need to be repaired to enable their forms to be properly understood.

3 X-radiographs that are overloaded with artefacts can be confusing to interpret. There should also be sufficient space between items to allow for labelling (*see below*).

4 Optimum X-radiography is best achieved when the surfaces of the artefacts are in close proximity to the film in order to minimize distortions. This is one reason why it is preferable to remove all or most of the packaging surrounding the artefacts, although very small or fragile items can be exceptions to this.

5 Distortions in the image can also occur owing to the radiation beam angle.

6 The exposure required is also affected by the film-to-focus distance (FFD), which is the distance between the film and the focal spot of the X-ray tube.

7 Dimensional and other distortions need to be considered if artefacts are illustrated from the X-radiographs.

Film development

The development of the film is an important part of the process for high quality, archival radiographs. A rigorous darkroom routine is essential, from development through to thorough washing and drying. Manufacturers' processing data sheets and darkroom hints are useful sources of information and can be downloaded from their web pages. There are health and safety requirements for working with the processing chemicals (The Control of Substances Hazardous to Health Regulations (COSHH) 2002). Information on the safe disposal of chemicals can be found in their Material Safety Data Sheets and must comply with local authority regulations on waste.

A high level of attention to detail is critical when developing X-radiographic film to produce useful images. If it is lacking, the investment made in the exposure process may be wasted. The X-radiographic image should have a uniformly black background and the lack of a black background is diagnostic of a badly processed film. The use of exhausted processing chemicals produces a streaky background in various shades of brown. X-radiographs with this appearance have no value in the archive and should not be accepted. It can be avoided by the rigorous monitoring of processing chemicals.

Film labelling

The processed films require clear labelling in a tidy and small format so as not to interfere with the recorded image. White ink is commonly used to mark the film directly, although it is worth noting that this method of marking will not be copied during any digitisation process. Certain minimum information, such as the designated X-ray film number, the accession numbers of the artefacts examined, and diagrammatic representations showing orientations of the artefacts plus other relevant information, must be recorded with the X-radiograph. This information, together with exposure parameters, will also be recorded on the outer protective sleeve of the X-radiographs (*see below*), as well as in a log book for the X-ray equipment. The data forms part of the 'X-ray archive' and can be useful for the interpretation of the X-radiograph. The designated radiograph numbers for each item or groups X-rayed will form part of the site archive and the research archive, as separate 'X-ray catalogues' and through cross-reference to the object catalogue (English Heritage 1991, A3.1.1, A6.1.1).

It is also worth adding the X-ray film numbers to the finds bags or labels as this provides a quick method to retrieve the correct radiograph when examining objects, and may be a requirement of the recipient museum.

Film protection

The emulsion layers of the film are very vulnerable to scratching and to other damage through handling, such as finger marks. For protection, transparent covers such as polyester sleeves are invaluable, particularly when handling the finds and the X-radiographs together during assessments and many conservation procedures, for example.

It is advisable to send objects and their X-radiographs separately if they are transferred between project members via courier services. Nor should they be boxed together: their storage requirements differ and the potential damage to X-radiographs from contact with dust and other particles should be avoided.

Storage

The recommended environmental conditions for processed X-radiographs are 20 – 50% relative humidity at a temperature less than 25°C for medium-term storage and less than 21°C for long-term (extended) storage (Brown forthcoming; British Standards Institution 2000).

The enclosures for the films should be inert, acid-free sleeves or envelopes. Commonly, transparent polyester sleeves are used, together with outer acid-free paper or card envelopes, but the requirements of the recipient museum or repository should also be considered. The outer paper or card envelope can be printed or labelled in archival-quality ink. Any plastic sleeves should be inert and free of plasticiser. Chlorinated nitrated or plasticised sheetings are highly unsuitable and should not be used (British Standards Institution 2000; 2001), nor should Glassine envelopes.

7. How to view the X-radiographs

Viewing radiographs in the correct conditions is important to fully appreciate the range of information available. Ideally, they are viewed in a room where light levels are reduced to a minimum, and the radiograph is 'back-lit' on a light-box. The unused areas of the front panel of the light-box should be blanked off. The temptation to view and attempt the interpretation of carefully produced images by squinting at them against an inappropriate light source, such as a window or desk lamp, should be avoided, as it is impossible for the eye to cope effectively with such wide variations in light levels. A low-power lens such as a photographer's loupe (X4–X8 magnification) can be useful for closely examining the detail in an image.

Project managers should ensure that staff experienced in the interpretation of X-radiographs are engaged in the analysis of the assemblage. The radiographs should be consulted when objects are illustrated to ensure that the form of the actual items are depicted, rather than the shape of the covering corrosion products.

X-radiographs might often be the best way to publish artefacts, particularly when they are very accreted or possess intricate technological features. Complex objects with internal workings such as lock mechanisms (eg Egan 1998, 109, fig 83) and other items, including the York Coppergate helmet (Spriggs 1992, 901), knives (eg Cowgill *et al* 1987, pls 2 and 5), and pattern-welded blades (eg Lang and Ager 1989) all benefit from the publication of X-radiographs. Finds catalogues can also be enhanced by judicious use of radiographs (eg Haughton and Powlesland 1999).

8. How much should it cost?

It is often necessary to provide an estimate of the cost for X-raying finds from an excavation at the project planning stage, before the quantity of material is known. An estimate will anticipate the volume of finds based on past experience for the site type and period within the region. Of course if the volume of finds is known then a more precise costing can be gained from the organisation that will be undertaking the work.

The cost for X-radiography will include materials (the film and developing costs), time (labour), plus any overheads such as laboratory and equipment expenses not accounted for in the previous costs (eg X-ray equipment maintenance costs and compliance with health and safety requirements). The time element will depend on factors such as the condition of the material (does it require repairing before X-raying?), the packaging methods (which can affect handling time), annotating the radiographs and their paper or digital records, the desirability of multiple exposures, the size of objects, and so on.

Costs can be affected by other, less obvious, factors. When considering several tenders one should be aware that the lowest prices might not always provide the best value for money. It is important that not only high quality radiography but also appropriate handling of the material is specified and undertaken. Adequate packaging to ensure the material is safely transported is necessary and will affect the overall cost.

Indicative costs (in 2005) for the commonly employed 180 × 240mm size X-ray film are as follows:

- materials and laboratory expenses – £4 to £5 per film
- time (labour) – typically around eight radiograph films can be completed in a day where small items are X-rayed (inclusive of exposure, development and marking-up). A greater number of radiographs can usually be completed in a day where large items or large groups are X-rayed.

The numbers of objects per film will obviously vary as indicated above, but typically the following examples may apply for each 180 × 240mm film as a rough guide:

- 20 to 40 coins (less than 20 per film if multiple exposures are made, more than 40 coins per film in some circumstances)
- 3 domestic knives (assuming 2 exposures of each knife)
- 1 complex barrel padlock (at 3 orientations)
- 30 nails (less than 30 per film if these are large, or if they are bulky or complex groups with mineralised wood attached, such as those from coffins. Conversely, perhaps 100 or more individual hobnails would fit on an X-ray film, depending on the method of numbering, or a single hobnailed shoe sole).

9. Where to get help

Advice on facilities and laboratories available for commercial and other work can be obtained from the following sources:

1 local archaeological conservation laboratory services through local authority and county museum services, universities and other institutions, and through discussion with the other finds specialists involved in the project 'core team'

2 English Heritage, Fort Cumberland, Portsmouth (tel: 02392 856704)

3 The Conservation Register of the Institute of Conservation (formerly United Kingdom Institute for Conservation, UKIC). This is a register of privately practising conservators: Conservation Register, c/o Institute of Conservation, 3rd Floor, Downstream Building, 1 London Bridge, London SE1 9BG tel: 0207 785 3804 e-mail: info@conservationregister.org.uk www.conservationregister.com

4 English Heritage Regional Science Advisors, listed below with their regions:

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Bibliography

Bayley, J, Dungworth, D and Paynter, S 2001 *Archaeometallurgy*. English Heritage Centre for Archaeology Guidelines, 2001/01. English Heritage Publications

Brickstock, R J 2004 *The Production, Analysis and Standardisation of Romano-British Coin Reports*. London: English Heritage Publications

British Standards Institution 2000 *Imaging Materials – Processed Safety Photographic Films – Storage Practices, BS ISO 18911: 2000*. London: British Standards Institute

British Standards Institution 2001 *Imaging Materials – Processed Photographic Films, Plates and Papers – Filing Enclosures and Storage Containers, BS ISO 18902: 2001*. London: British Standards Institute

Brown, A forthcoming 'The documentary archive', in *UKIC Guidelines for the Preparation of Excavation Archives for Long-Term Storage* (2 edn). London: UKIC Archaeology Section

Canti, M G 2003 'X-ray studies of the sediments', *in* Brennand, M and Taylor, M 'The Survey and Excavation of a Bronze Age Timber Circle at Holme-next-the-Sea, Norfolk, 1998–9', *Proceedings Prehistoric Society* **69**, 42–3

Cowgill, J, de Neergaard, M and Griffiths, N 1987 *Knives and Scabbards*. Medieval Finds from Excavations in London, 1. London: HMSO

Department of the Environment 1990 *Planning Policy Guidance: Archaeology and Planning*. PPG 16. London: HMSO

Department of the Environment 1994 *Planning Policy Guidance: Planning and the Historic Environment.* PPG 15. London: HMSO

Egan, G 1998 *The Medieval Household Daily Living* c *1150*–c *1450*. Medieval Finds from Excavations in London, 6. London: The Stationery Office

English Heritage 1991 *Management of Archaeological Projects* (2 edn). London: English Heritage

English Heritage 2002 *Environmental Archaeology: A Guide to the Theory and Practice of Methods, from Sampling and Recovery to Post-excavation.* English Heritage: Centre for Archaeology Guidelines 2002/01

English Heritage 2004 *Geoarchaeology: Using Earth Sciences to Understand the Archaeological Record*. English Heritage

Halmshaw, R 1986 *Industrial Radiography*. Agfa-Gevaert

Haughton, C and Powlesland, D 1999 *West Heslerton, The Anglian Cemetery, Vol ii. Catalogue of the Anglian Graves and Associated Assemblages.* Yedingham: The Landscape Research Centre

Institute of Field Archaeologists 2001 *Standard and Guidance for the Collection, Documentation, Conservation and Research of Archaeological Materials*. Reading: IFA

Kodak 1985 *Fundamentals of Radiographic Photography, Vol III, Radiographic Quality*. London: Kodak Ltd

Kodak 1987 *Fundamentals of Radiographic Photography, Vol II, X-ray Recording Materials*. London: Kodak Ltd

Lang, J and Ager, B 1989 'Swords of the Anglo-Saxon and Viking Periods in the British Museum: A Radiographic Study', *in* Hawkes, S C (ed), *Weapons and Warfare in Anglo-Saxon England*, Oxford University Committee for Archaeology Monograph 21, 85–122. Oxford: OUCA

Lang, J and Middleton, A (eds) 2005 *Radiography of Cultural Material* (2nd edn, revised). London: Elsevier

O'Connor, S and Maher, J 2001 'The digitisation of X-radiographs for dissemination, archiving and improved image interpretation'. *The Conservator* **25**, 3–15

O'Connor, S, Maher, J and Janaway, R 2002 'Towards a replacement for xeroradiography'. *The Conservator* **26**, 100–114

Ottaway, P 2003 'Knives', in Hardy, A, Dodd, A, and Keevill, G D, *Ælfric's Abbey; Excavations at Eynsham Abbey, Oxfordshire, 1989–92*, Oxford: Oxford Archaeology, Thames Valley Landscapes 16, 271–273

Quinn, R A and Sigl, C C (eds) 1980 *Radiography in Modern Industry* (4 edn). Rochester, New York: Eastman Kodak Company

Richards, J and Robinson, D 2000 *Digital Archives from Excavations and Fieldwork: Guide to Good Practice* (2 edn). Oxford: Oxbow, and available at http://ads.ahds.ac.uk/project/goodguides/excavation (accessed 20 July 2005)

Roman Finds Group and Finds Research Group AD 700–1700, 1993 *The Guidelines for the Preparation of Site Archives and Assessments for All Finds Other than Fired Clay Vessels.* Roman Finds Group and Finds Research Group AD 700–1700

Spriggs, J A 1992 'Conservation – approach and methods', *in* Tweddle, D *The Anglian Helmet from 16–22 Coppergate*. The Archaeology of York. The Small Finds, 17/8, 894–901. London: CBA

Starley, D 1995 *Hammerscale*. Historical Metallurgy Society Archaeology Datasheet 10 (www.hist-met.org)

Watson, J and Edwards, G 1990 'Conservation of Material from Anglo-Saxon Cemeteries', *in* Southworth E (ed), *Anglo-Saxon Cemeteries: A Reappraisal*. Proceedings of a Conference held at Liverpool Museum 1986, 97–106. Stroud: Alan Sutton

Health and safety

The Ionising Radiations Regulations 1999 (Statutory Instrument 1999 No. 3232). HSE. The Stationery Office Ltd

The Control of Substances Hazardous to Health Regulations 2002 (Statutory Instrument 2002 No. 689). HSE. The Stationery Office Ltd

The Control of Lead at Work Regulations 2002 (Statutory Instrument 2002 No. 2676). HSE. The Stationery Office Ltd

09234 6/1/06 10:12 Page 16

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Cover figure: Post-medieval padlock as excavated and with the padlock mechanism revealed through X-radiography.

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