AN

ARCHAEOLOGIST'S GUIDE TO X-RADIOGRAPHY

AT THE MARYLAND ARCHAEOLOGICAL CONSERVATION LABORATORY

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INTRODUCTION

The Maryland Archaeological Conservation Laboratory (MAC Lab) at Jefferson Patterson Park and Museum (JPPM) opened in 1998 as a state-of-the-art curation, conservation, and research facility for archaeological collections. It is the archaeological repository for the collections of the Maryland Historical Trust and various federal agencies, and the conservation department treats artifacts in-house and from outside contracts. Among the tools used at the MAC Lab on a weekly basis is a large walk-in x-radiography machine.

X-rays can be an invaluable tool for archaeological lab managers, conservators, and collections managers. They are non-destructive, relatively affordable, and result in a digital image or stable film that can be archived. Despite these truths, x-radiography is underutilized in archaeology, often because people think it is too expensive or inaccessible. This needs to change.

Among its many other applications, x-rays can be used to document corroded bulk metals, such as nails, that will never be a priority for conservation and will therefore deteriorate if curated. This documentation can be used as part of a responsible sampling and discard strategy for collections from historic sites, saving space, decreasing curation box fees, and offering archaeologists better artifact identifications in the process. At the MAC Lab, we have had a client use this strategy to save money, because the funds spent on x-rays were significantly less than the curation box fees that would have been charged to store the heavily corroded nails that were x-rayed and sampled (González and Salvato 2019). That inspired us to try harder to get the word out about how x-radiography can contribute to a more sustainable future for archaeological curation.

This guide is intended for any archaeologist processing collections that could benefit from x-radiography. Although many materials can be x-rayed, this guide is focused on metal artifacts. Part I outlines and illustrates what information x-rays offer archaeologists. Part II includes an in-depth discussion of the use of x-rays for cataloging and as part of a sampling and discard strategy. Finally, Part III discusses the specifics of x-radiography services at the MAC Lab, including pricing.

We wish to be clear, however, that we want more archaeologists to use x-radiography regardless of whether they hire the MAC Lab's services. For the good of collections and archaeology as a discipline, we encourage people who do not live or work near an archaeological facility with x-radiography to reach out to your local university, hospital, large animal veterinarian, dentist, or even a technician manning the x-ray belt at the local courthouse or airport. You will be surprised how many x-ray technicians in other fields may be enthusiastic about archaeology and willing to offer to help.

THE FUNDAMENTALS OF READING ARTIFACT X-RAYS: DENSITY AND 2D

There are two primary principles to keep in mind when looking at artifact x-rays: **Density** and **2-Dimensionality**.

DENSITY

In the most basic terms, x-rays are an illustration of density. The denser an object is, the brighter it will be on the x-ray. Corrosion is typically less dense than any remaining metal, so when corrosion hides an artifact to the visible eye, x-rays help you see the core metal artifact because it is denser than the corrosion that obscures it. Different types of metal will also differ in density, which will be visible on an x-ray (See Section 1.4 below).

2-DIMENSIONALITY

Artifacts are 3-dimensional, but the images resulting from x-rays are only 2-dimensional, and that can be tricky to read. Sometimes when you see a bright spot on the x-ray it has less to do with the level of preservation of metal than with the orientation of the artifact.

For objects that are large or do not lie flat, the surface of the object that is closest to the x-ray film will be more accurately represented in the resulting image. The part of the artifact that is farthest away from the film's surface will be less sharp in focus and slightly magnified in size. This is a crucial consideration when measurements are being taken using the x-ray image (Section I.8) and when x-rays are being used as documentation prior to discard (Section III).

For artifacts that do not lie relatively flat, it may be necessary to take x-rays from multiple angles to get better documentation. The less "flat" an object is, the greater the need to have the artifacts at hand to help understand the x-ray (Figure 1).

FIGURE 1: THESE TWO CURB BITS ILLUSTRATE HOW X-RAYS DIFFER WHEN ARTIFACTS LIE FLAT (LEFT) COMPARED TO THOSE THAT DO NOT (RIGHT). THE LATTER HAS A MOUTHPIECE THAT POINTS UP WHEN THE BIT IS PLACED WITH THE BOSS SOMEWHAT FLAT ON THE FILM. WHILE THE CHEEK PIECE IS SHOWN WITH DECENT ACCURACY, THE VISUAL REPRESENTATION OF THE MOUTHPIECE IN THE X-RAY IS DISTORTED BY THE PERSPECTIVE.

LEARNING THE LINGO

If working with an expert on x-rays, here's a distinction worth noting to make sure you're speaking the same language:

When referring to the services you want or the technique being used, it is correct to say **x-radiography,** not the shortened term **x-ray. X-rays** are the actual invisible-to-the-eye radiation waves that are directed at your artifact when performing **x-radiography**. The films or digital images you get as a final product are also called **x-rays.**

PART I: WHAT CAN X-RAYS DO FOR ARCHAEOLOGISTS?

X-radiography's most exciting archaeological superpower is its ability to penetrate concretions to reveal the artifact within. In Maryland, the most common use is seeing through ferrous corrosion on iron artifacts, but it can also help with other metal and non-metal artifacts. The following illustrated list is not comprehensive but offers a good idea of what archaeologists can expect to learn from an x-ray.

IDENTIFICATION OF CONCRETED ARTIFACTS

While it is not the case that every ball of corrosion hides an easily identifiable artifact, many do. Here are just a few examples (Figures 2-6).

FIGURE 2: COPPER ALLOY SHOE BUCKLE FRAGMENT SHOWN BEFORE TREATMENT, X-RAY, AND AFTER TREATMENT.

COURTESY NAVAL DISTRICT WASHINGTON, NAVAL AIR STATION PATUXENT RIVER

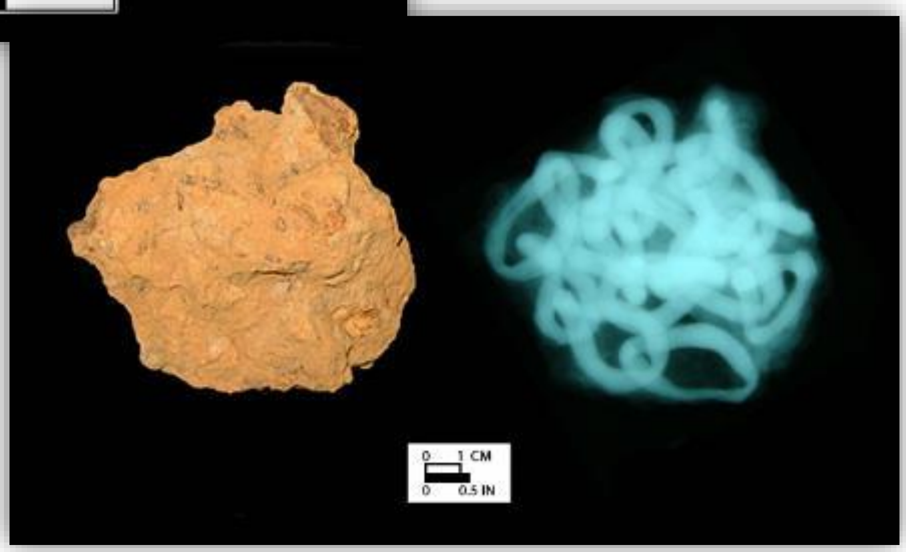


FIGURE 3: IRON CHAIN LINK; AS FOUND AND X-RAY.

COURTESY U.S. ARMY GARRISON, ABERDEEN PROVING GROUND

PRO TIP

Lay out the artifacts for x-radiography in a tray or box that you can leave untouched until the tray and x-ray can be viewed side-by-side. This is the best way to avoid finding a great artifact on an x-ray but not being able to tell which blob it belongs to.

Figure 4: Ferrous blob that x-radiography revealed to be two large 17th-century clothing hooks, such as the conserved example shown (top right).

Courtesy Naval District Washington, Naval Air Station Patuxent River Webster Field

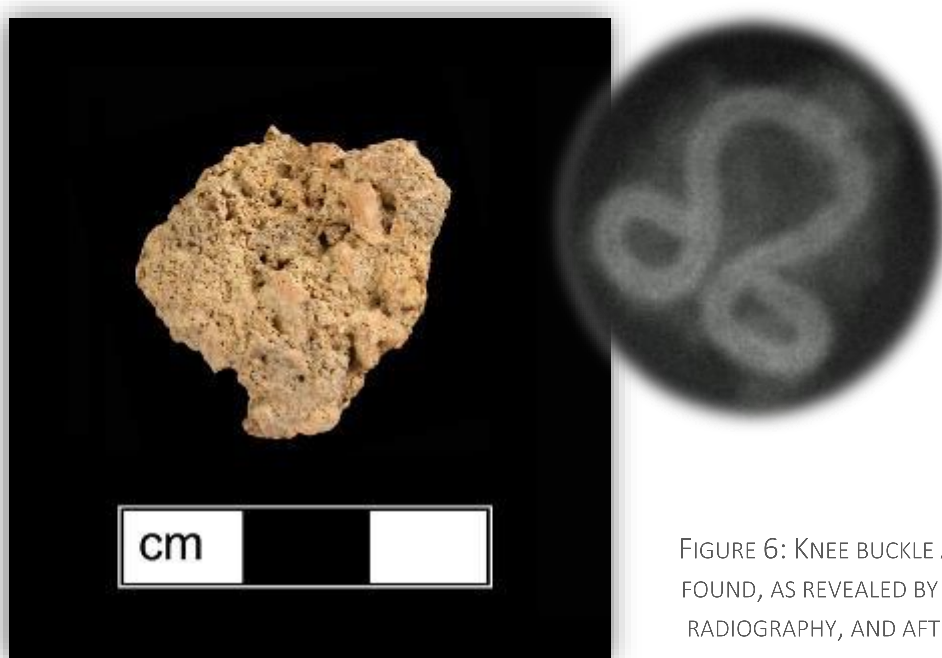


Figure 5: Ferrous clothing eye, as found and as revealed by x-radiography.

Courtesy Naval District Washington, North Severn

Figure 6: Knee buckle as found, as revealed by x-radiography, and after conservation.

Courtesy of the Delaware Dept. of Transportation and the Federal Highway Administration

SURFACE DETAILS AND MARKS

X-rays are useful at revealing surface details such as decoration, lettering, and maker's marks (Figures 7-11).

FIGURE 7: LEAD SEAL WITH LETTERING; BEFORE TREATMENT, X-RAY, AND AFTER CONSERVATION.

FIGURE 8: THIS BUTTON WAS FOUND IN A CLUMP OF CORRODED BUTTONS, PINS, AND TEXTILES AND HAS A HEAVILY CORRODED SURFACE. AFTER X-RADIOGRAPHY IT WAS IDENTIFIED AS BELONGING TO A CONNECTICUT DIVISION'S CIVIL WAR UNIFORM.

PHOTOS BY KERRY S. GONZÀLEZ, COURTESY CITY OF FREDERICKSBURG, VA.

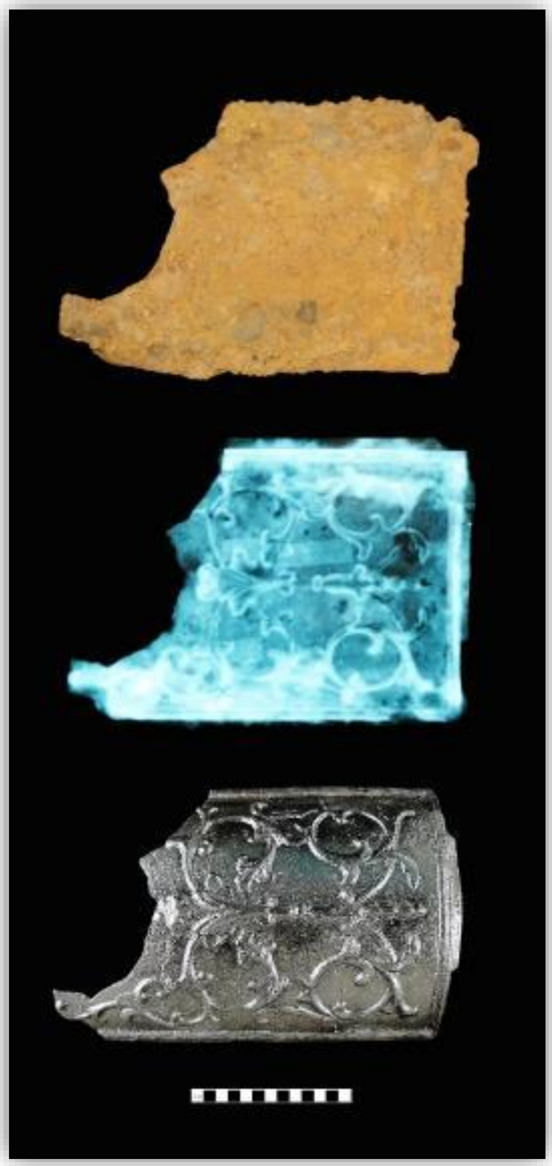


Figure 9: This cast iron stove part is heavily decorated, but all decoration was obscured by corrosion when excavated. Shown before treatment, as revealed by x-radiography, and after conservation.

Courtesy U.S. Army Garrison, Aberdeen Proving Ground

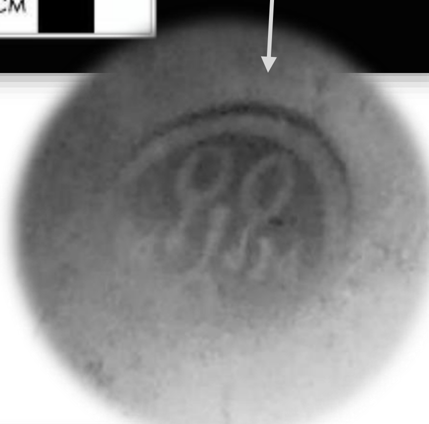


Figure 10: X-rays of this spoon reveal a fairly clear maker's mark of the initials "MM" flanking three small spoons.

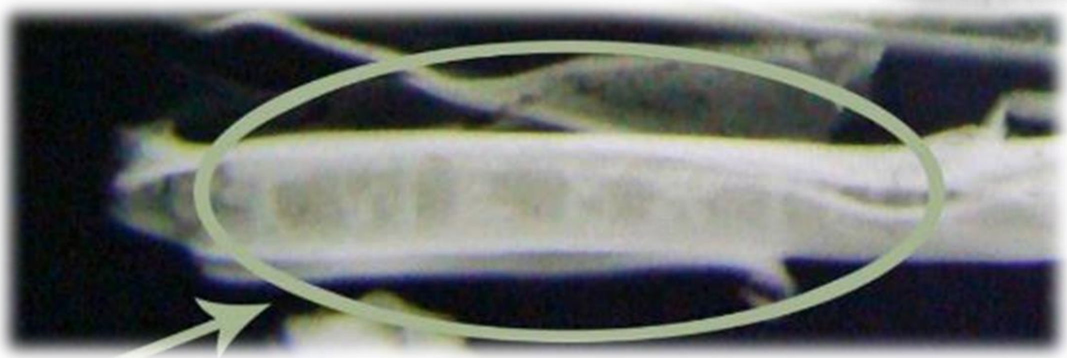


Figure 11: Window leads are sometimes marked on the inside with initials and dates, but they are often twisted, brittle, and difficult to open. X-rays may show which leads are marked. This may prevent the need to open them if the mark is legible or help identify leads that are more likely to have marks if they are opened.

THE CORROSION PROCESS

Corrosion is a natural process where a metal is reverting to a more chemically stable form. For corrosion to take place an object must be exposed to oxygen, water, and an electrolyte which is present in varying quantities in the burial environment. Corrosion occurs as metal ions join with oxygen to form “rust” while hydrogen atoms in water react to form acidic compounds that further deteriorate the metal and expose more metal ions to oxygen. These oxides are larger in volume than refined metal and produce large crusts that can trap soil and other materials from the burial environment and obscure the original object within.

However, these crusts aren’t necessarily bad. If the corrosion process has stabilized and is no longer active, this layer provides a degree of protection to the remains of the artifact within. For this reason, metal artifacts should not be cleaned after excavation without additional conservation measures. Disturbing the protective layers may initiate a new corrosion cycle and cause further material loss.

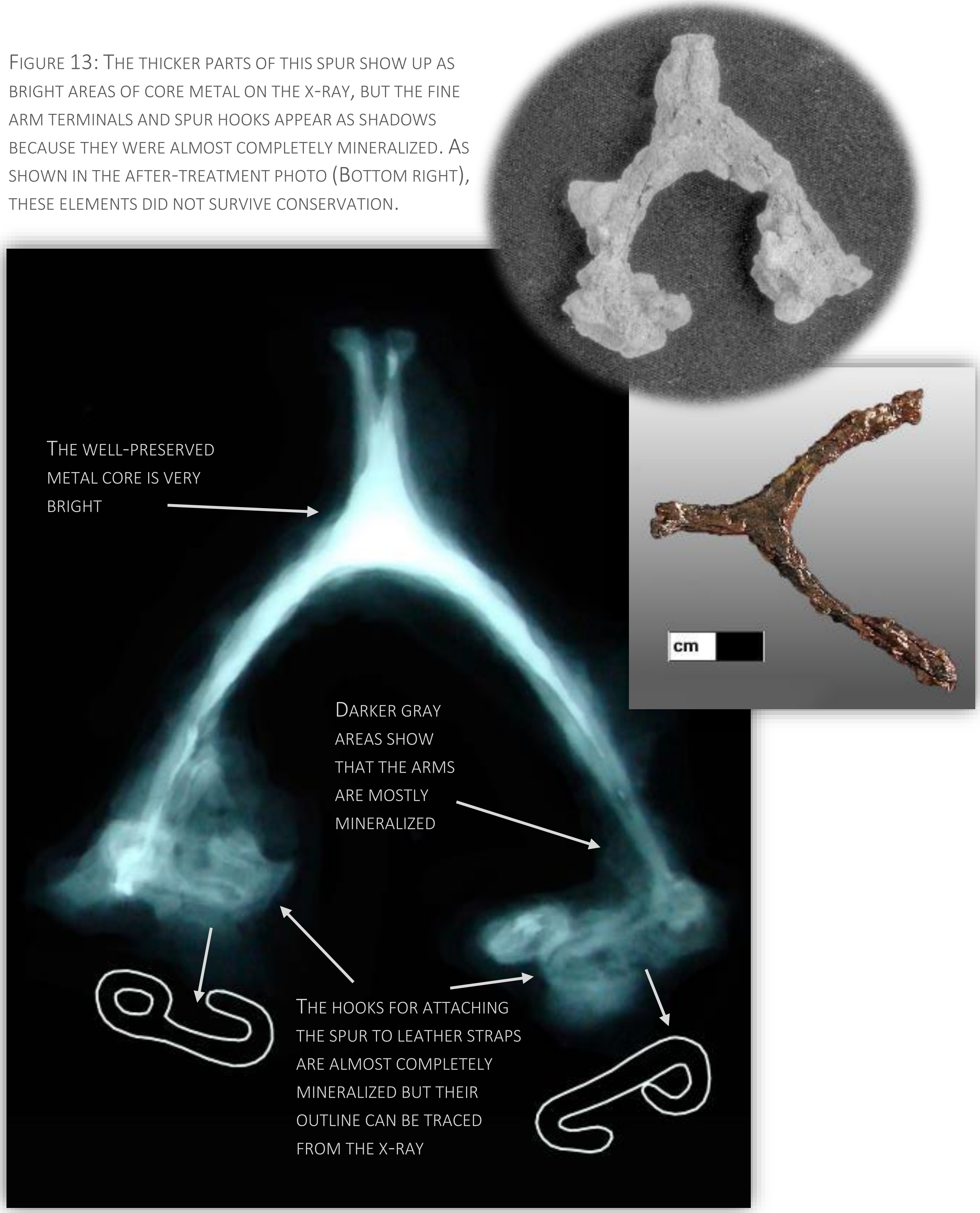
DEGREE OF PRESERVATION

Some metal artifacts become so mineralized that they appear only as a shadow or even an empty void. X-rays may show the outline of an artifact even if it is mostly or completely deteriorated (Figures 12-13). This is useful to conservators because it lets them know what to expect during treatment. It is important for researchers because it allows the documentation of attributes that will never be visible to the naked eye because they will not survive conservation treatment. Finally, this is important for collections managers who must decide how to allocate precious conservation dollars. If there is little left of an artifact to save, it may be best to put funds into something that has a better chance of surviving treatment.

FIGURE 12: THIS PAIR OF SMALL DECORATIVE EMBROIDERY SCISSORS WAS DISCOVERED THROUGH X-RADIOGRAPHY AND SENT FOR CONSERVATION TREATMENT. WHILE THE X-RAY SHOWS INTRICATE DETAILS, IT ALSO SHOWS HOW MINERALIZED THE SCISSORS WERE. INSTEAD OF BRIGHT AREAS INDICATING INTACT CORE METAL, THE HANDLES ARE A FOGGY GRAY. CONSERVATORS WERE ABLE TO SAVE THE SCISSORS, BUT UNABLE TO REVEAL THEIR ORIGINAL SHAPE.

COURTESY NAVAL DISTRICT WASHINGTON, NAVAL AIR STATION PATUXENT RIVER

Figure 13: The thicker parts of this spur show up as bright areas of core metal on the X-ray, but the fine arm terminals and spur hooks appear as shadows because they were almost completely mineralized. As shown in the after-treatment photo (Bottom right), these elements did not survive conservation.



MATERIAL COMPOSITION

Because x-rays show density, they can help with the identification of material types (Figures 14 and 16). Lead is especially bright, copper alloy tends to be both bright and sharp, and corroded iron has blurred edges.

Figure 14: This pistol found in the Nottoway River illustrates different materials in one object. The wood handle is not very dense, so it shows as a dark area (A). Small copper alloy flintlock elements are bright and sharp (B), but the copper alloy powder pan and iron corrosion are so dense that it creates an area too bright to see any definition at the current x-ray settings (D). The lead lining in the hammer jaws that holds the gunflint is bright and defined (C). Finally, iron preservation is evident in the gun barrel (E), but the fully deteriorated butt cap shows as a faint cloudy outline on the x-ray (F).

Courtesy of the Southampton County Historical Society

DENSITY OF DIFFERENT METALS AND ALLOYS

While the thickness of an object will impact the relative brightness of an x-ray, so will the density of its elemental composition. The following chart shows how metals that are likely to be found archaeologically compare by density. Metals with high density block more x-rays, making them appear as a bright flare on an x-ray. The high density of lead is the reason it is used to line the MAC Lab's x-ray room, protecting staff from exposure to the invisible x-rays.

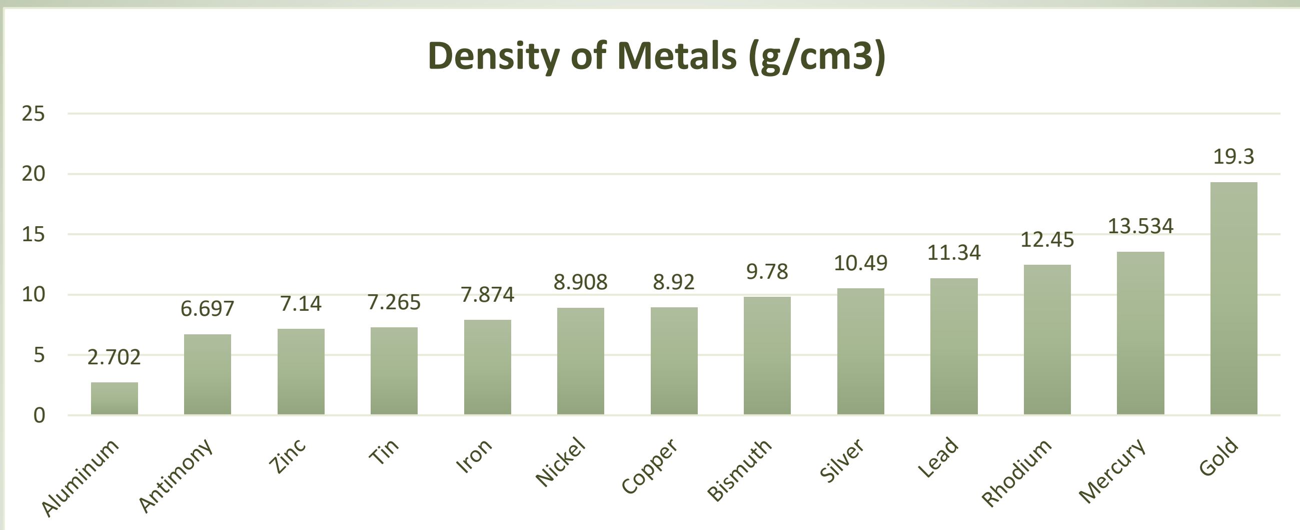


FIGURE 15: METALS COMMONLY FOUND ARCHAEOLOGICALLY ARRANGED IN ORDER OF INCREASING DENSITY.

Archaeological metals rarely consist of only a single element. Instead they are comprised of alloys made for different purposes. Determining the precise elemental composition of archaeological metals requires specialized analysis such as X-ray fluorescence (XRF), but with a little knowledge of common historic alloys a standard x-ray will usually help narrow down the possibilities. Artifacts made by hand or cast in batches do not lend themselves to hard and fast rules, but Table 1 offers some general characteristics of historic alloys archaeologists are likely to encounter. Compare these to the chart above to get an idea about the relative densities of different alloys. For example, pewter is primarily tin with additives such as lead, copper, and bismuth, all of which have relatively high densities. Pewter will therefore appear brighter than many other metals, on an x-ray, and may require different x-ray settings to get a quality image (See Figure 17). Similarly, artifacts that have been gilt with a thin layer of gold might exhibit bright spots on an x-ray where gilding remains because gold is so dense.

TABLE 1: WHILE MUCH VARIATION IN PERCENTAGES EXISTED OVER TIME, THIS TABLE OFFERS GENERALITIES ABOUT THE ELEMENTAL COMPOSITION OF VARIOUS ALLOYS LIKELY TO BE RECOVERED BY ARCHAEOLOGISTS. FERROUS ALLOYS ARE EXCLUDED BECAUSE THEIR NON-IRON COMPONENTS, SUCH AS CARBON IN STEEL, TEND TO BE FOUND IN SUCH LOW PERCENTAGES THAT THE OBJECTS CAN BE SAID TO BE ALMOST ENTIRELY IRON.

Common Name	Primary Element	Typical Secondary Element(s)
Brass	Copper	Zinc
Bronze	Copper	Tin
German Silver/ Nickel Silver	Copper	Zinc, nickel, and maybe lesser amounts of lead or tin
Gold (14K, 18K)	Gold	Zinc, nickel, silver, copper, or rhodium (for hardness/durability)
Latten	Copper	Tin and zinc; possibly some lead
Pewter	Tin	Lead (historic pewter only), copper, zinc, antimony, bismuth
Sterling Silver	Silver (92.5%)	Copper
White Gold	Gold	Silver, zinc, nickel

X-ray Settings

Every x-ray unit is different so there are no standard settings that can be applied. When working with a new x-ray unit or operator, it may take some time to calibrate the settings, but once you have established a range of workable settings for your setup, the product will be well worth the effort.

When taking an x-ray the most important settings are:

1) **Distance** between the x-ray source and the object. Many x-ray cabinets have a fixed distance, but when using an x-ray chamber or portable x-ray the operator sets the distance. The power of the x-rays diminishes over distance, so the x-ray source should be as close as possible to the object while ensuring exposure of the film's entire surface area. Other settings will depend on the distance.
2) **Milliamp seconds (mAs)** control the quantity or amount of x-ray photons produced as well as the blackening on the x-ray film. For metals, we recommend starting with a high mA setting and making fine adjustments to the kV.
3) **Kilovolt peak (kVp)** controls the quality and contrast produced in the x-ray film. If an x-ray image is too bright and the image is under exposed, increase the kV setting. If the x-ray is too dark and the image is over exposed, decrease the kV to improve definition. If the image is too dark regardless of your kV adjustments, begin decreasing the mA setting.
4) **Exposure time** provides definition around the edges of your object, but it is less important than kV and mA settings.

If you're an archaeologist pursuing x-radiography, it isn't necessary to know how to deal with these settings; that is the job of the technician operating the machine. You do need to make sure that the settings used are documented, because the settings impact the resulting image. Think about recording mA, kVp, and exposure time settings for an x-ray the same as recording direction and context info for an excavation photo log.

Figure 16: This vial was found with a wad of textiles, buttons, and personal items that belonged to a Civil War soldier. When the wad was x-rayed, the vial's contents showed as a bright spot, suggesting that it was one of the 19th-century's popular mercury-based remedies.

Photo by Kerry González, Courtesy City of Fredericksburg, VA

PRO TIP

Try to group artifacts for x-radiography by material type and size so that technicians can choose the best settings. For example, flat can fragments are a lot less dense than a plow part, so even though both might be iron, they could call for different x-ray settings.

If there are only a few items that can all fit on one plate but they vary greatly in size or composition, ask about having different sections of the film exposed at different settings; a process that can be accomplished without changing out the film cassette (Figure 17). For composite artifacts, multiple x-rays using different settings may be needed to maximize the view of differing materials.

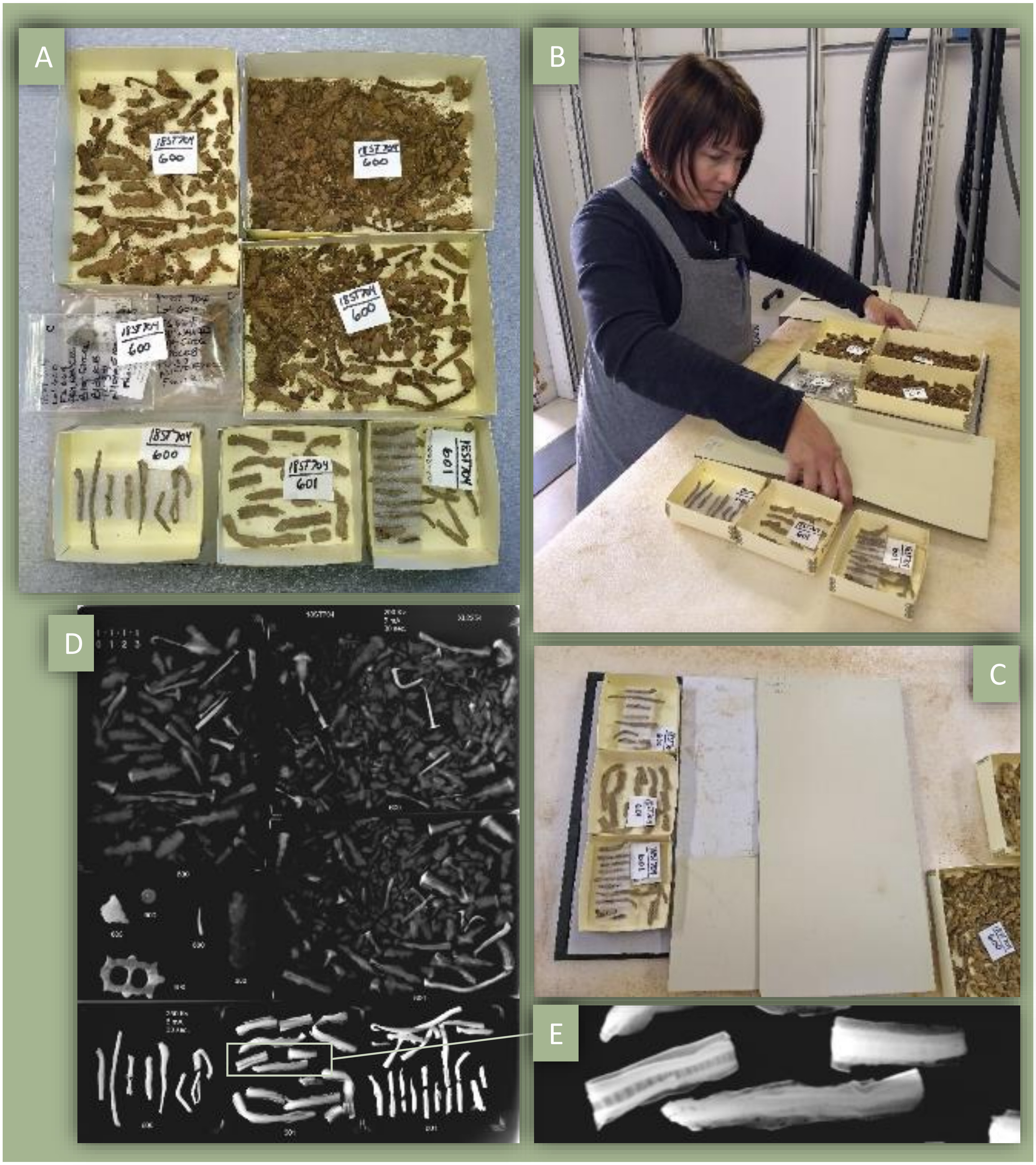


FIGURE 17: FOR THIS X-RAY LAYOUT, IRON AND COPPER ALLOY ARTIFACTS ARE GROUPED ON THE TOP TWO THIRDS OF THE PLATE WHILE WINDOW LEADS ARE LINED UP AT THE BOTTOM (A). CONSERVATOR FRANCIS LUKEZIC USED DIFFERENT SETTINGS FOR THE DIFFERENT MATERIALS. FIRST, SHE REMOVED THE WINDOW LEADS AND BLOCKED OFF THE PLATE WHERE THEY WOULD SIT, X-RAYING ONLY THE IRON AND COPPER AT 200KV (B). THEN SHE SWITCHED THE AREAS TO BE EXPOSED AND X-RAYED ONLY THE WINDOW LEADS AT 250KV (C). IN THE RESULTING X-RAY (D), IT IS POSSIBLE TO SEE WHETHER MARKS ARE PRESENT ON SOME OF THE WINDOW LEADS (E).

HIDDEN INTERNAL ELEMENTS

Archaeologists and conservators both try to adhere to a “do no harm” ethic and resist the temptation to break open artifacts even when there might be interesting internal elements to study. X-rays are a non-destructive way to examine internal elements that would otherwise be hidden (Figures 18-20).

Figure 18: This hollow silver reliquary pendant is designed to hold a sacred object such as a sliver of a saint's bone or a piece of the True Cross. The removable front connects with a thin band of metal soldered to the interior of the pendant at the top of the cross. It is held in place by a pin passing through the bottom. These connections are visible in the x-ray, but no sacred object is shown. It is possible that the relic was organic and either deteriorated in the burial environment or just does not show on the x-ray. Corrosion holds the pin in place so the reliquary has not been opened for fear of causing damage.

Courtesy Naval District Washington, Naval Air Station Patuxent River Webster Field

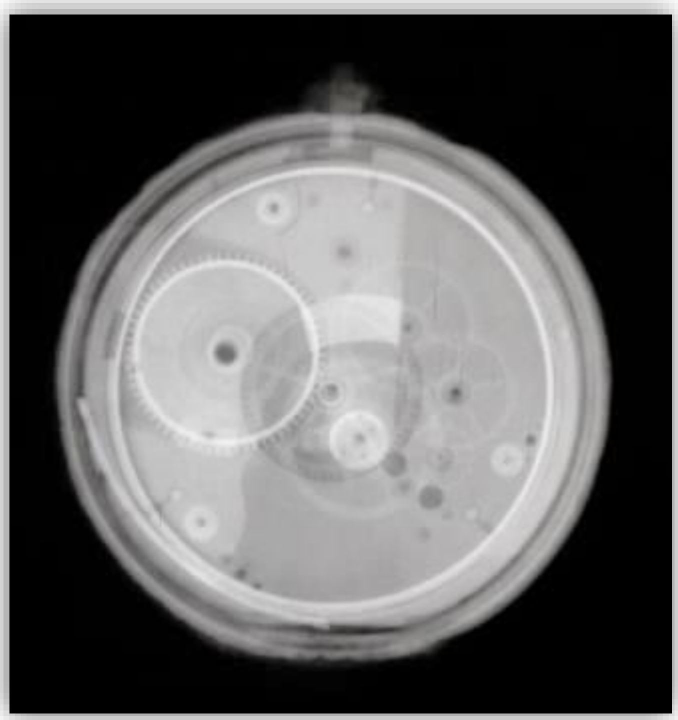


Figure 19: The many delicate gears within a pocket watch are readily visible in an x-ray.

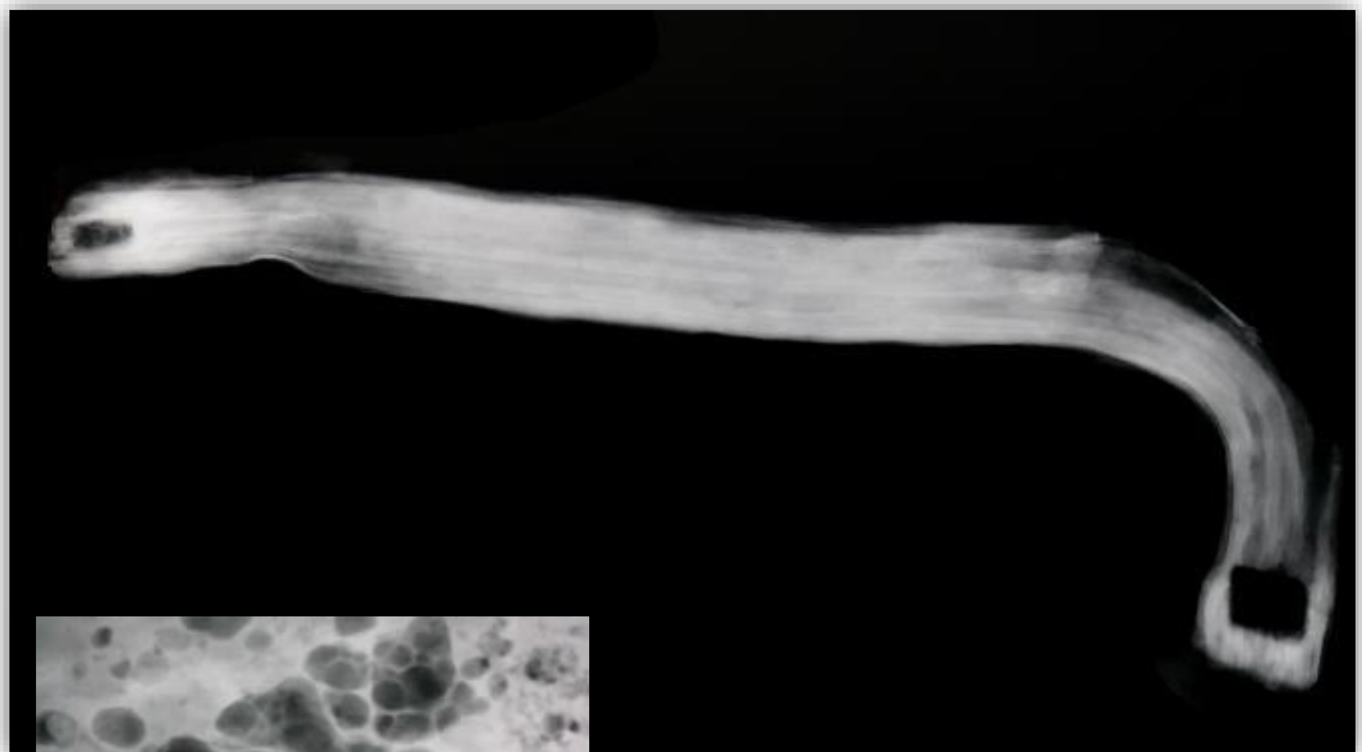
Courtesy of the City of Deadwood Archives

FIGURE 20: THESE TWO DOOR LOCKS LOOK QUITE SIMILAR ON THE OUTSIDE, BUT X-RAYS REVEAL DIFFERENCES BETWEEN THE MECHANISMS INSIDE.

LEFT: 18HA312/479 COURTESY U.S. ARMY GARRISON ABERDEEN PROVING GROUND. RIGHT: 18ST399/106 COURTESY OF THE NAVAL DISTRICT WASHINGTON, NAVAL AIR STATION PATUXENT RIVER

MANUFACTURING TECHNIQUES

X-radiography can be a useful tool to determine manufacturing techniques, which may have implications for interpretation and the curation needs of an object. For example, it is often easy to tell the difference between cast and wrought iron in an x-ray image (Figures 21-22). It is also possible to see joins/solders (Figure 23), and tool marks hidden by burnished surfaces due to the differing densities of the joining materials and the varying thicknesses of the worked areas.



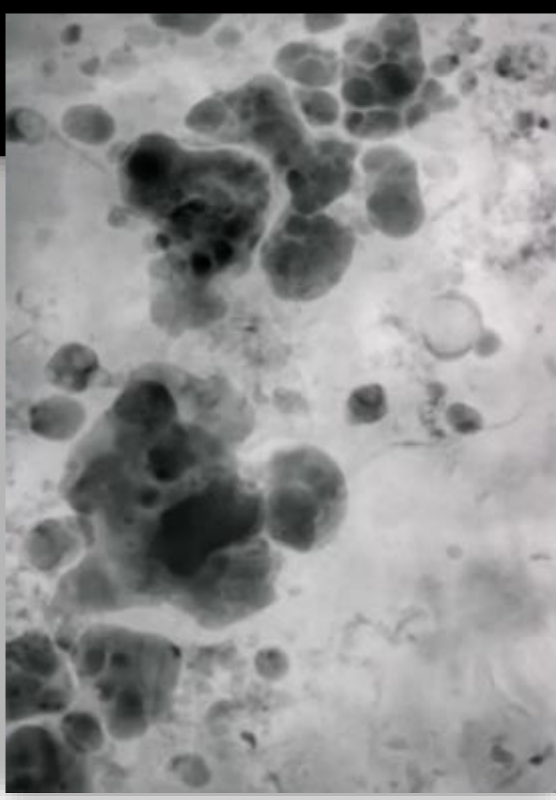


FIGURE 22: WROUGHT IRON IS CHARACTERIZED BY THE APPEARANCE OF LINEAR STRIATIONS ON THE X-RAY. IF THERE ARE ANY IMPURITIES REMAINING IN THE METAL AT THE TIME OF MANUFACTURE, THE HAMMERING, ROLLING AND WORKING OF THE IRON FORCES THE INCLUSIONS INTO AN ORGANIZED LINEAR STRUCTURE. THE INCLUSIONS OFTEN DETERIORATE MORE READILY THAN PURE IRON, CREATING A ROPEY OR WOOD-GRAIN APPEARANCE IN THE X-RAY.

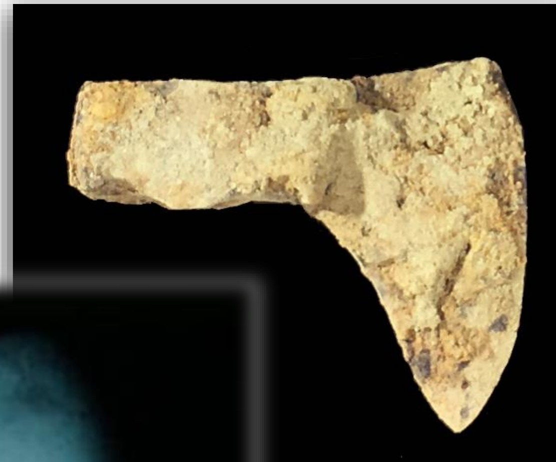
FIGURE 21: CAST IRON IS OFTEN REVEALED IN X-RAYS BY THE PRESENCE OF DARK POCKETS IN THE BODY OF THE OBJECT. THIS RESULTS FROM THE CASTING PROCESS AND THE RELATIVELY HIGH CARBON CONTENT NEEDED TO GIVE THE IRON THE NECESSARY WORKING PROPERTIES.

FIGURE 23: FROG GIG. ARROWS POINT TO AREAS THAT ARE HEAT-JOINED.

PHOTO BY KERRY S. GONZÀLEZ, COURTESY NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

ANOMALIES, DAMAGE, AND DEFECTS

X-rays can show various anomalies like manufacturing defects, structural weaknesses, and pest damage on organics (Figures 24-27). Even when damage and anomalies can be seen with the naked eye, x-rays help define them and show what's going on below the surface.



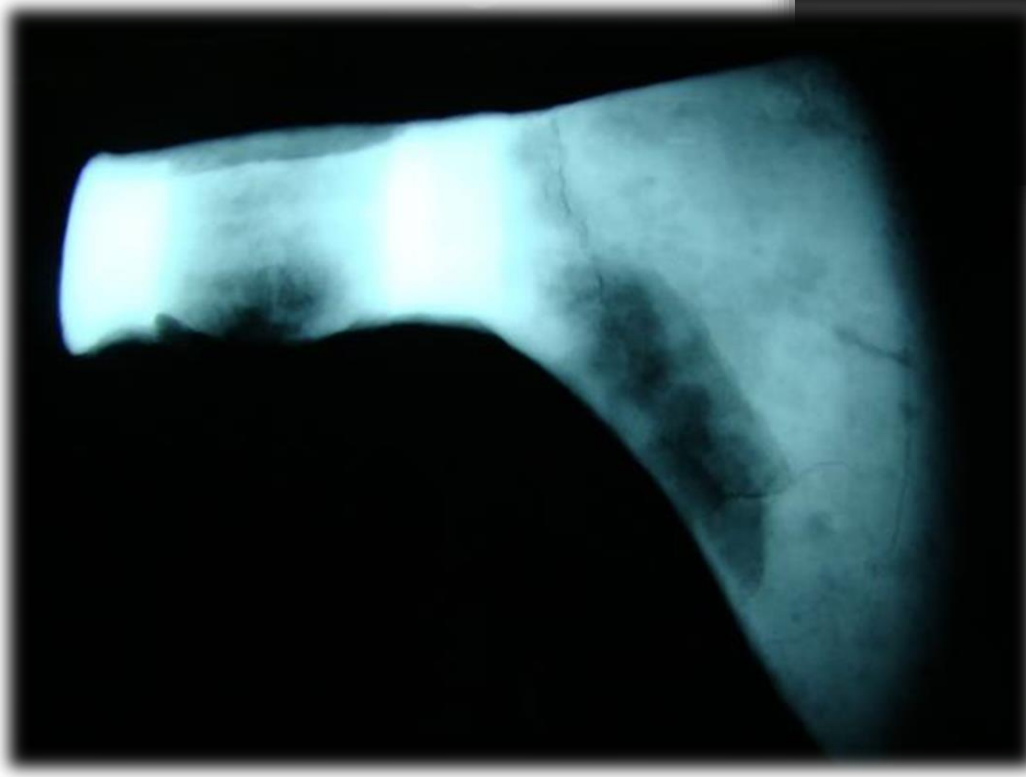


FIGURE 24: X-RAYS OF THIS AXE SHOW SEVERAL CRACKS THAT ARE PROBABLY RELATED TO USE-WEAR.

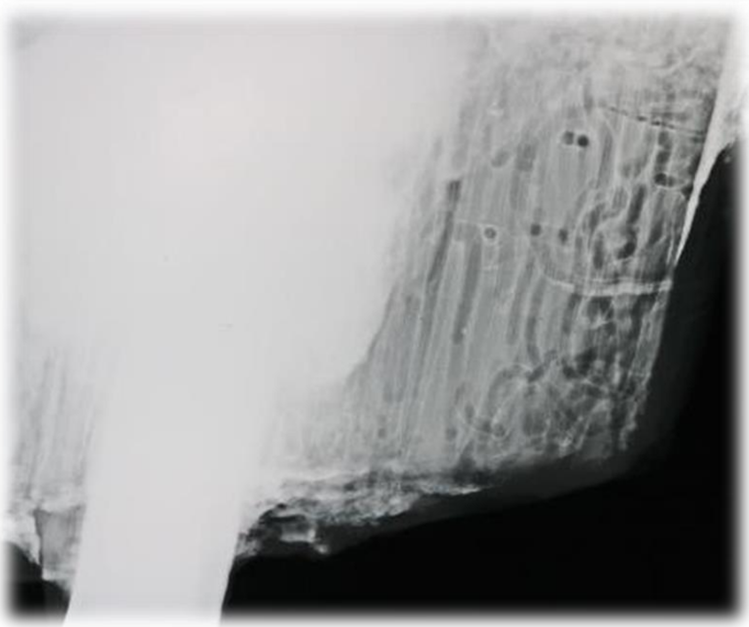


FIGURE 25: X-RAYS HELP WITH MORE THAN JUST METAL. IN THIS IMAGE THE X-RAYS REVEAL WORM DAMAGE ON A WOOD SHIP TIMBER WASHED UP ON ASSATEAGUE ISLAND.

COURTESY OF MARYLAND DEPARTMENT OF NATURAL RESOURCES

Figure 26: This image illustrates another type of casting failure caused by the metal being too cool. Flow lines are visible where the metal solidified unevenly.

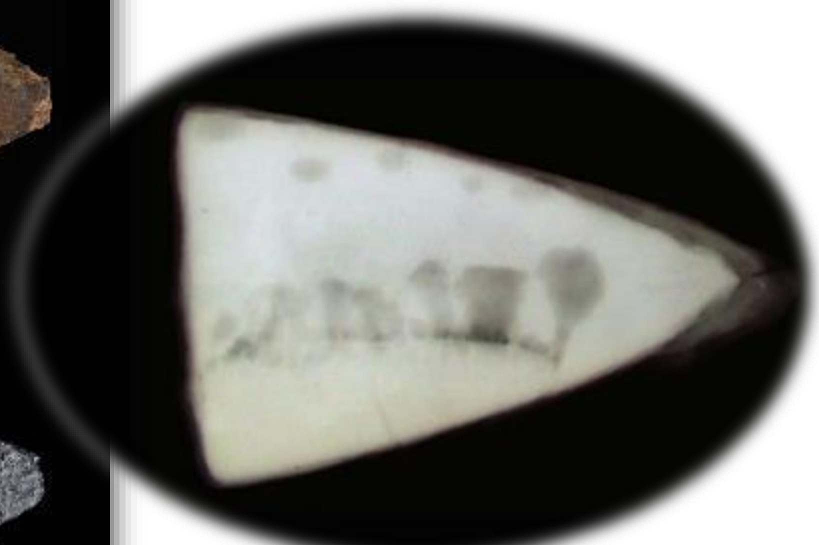


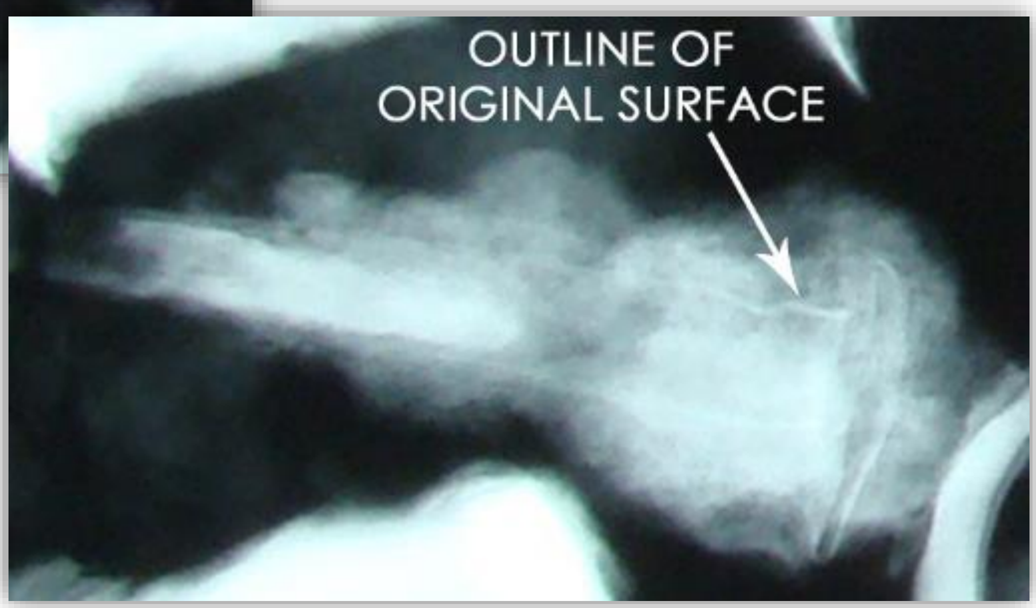
Figure 27: This insert for a box iron looks solid to the eye (shown before and after treatment at left), but X-rays revealed hollows resulting from the casting process. Instead of filling the mold completely, some trapped air remained when the cast metal cooled.

MEASUREMENTS

X-rays allow researchers to take accurate measurements of relatively flat objects that are otherwise impossible to measure because of corrosion crusts (Figures 28-30). X-ray images offer a 1:1 scale representation of the object as long as it is close to the surface of the x-ray film or digital sensor being exposed (Figure 31A). For larger objects that do not lie relatively flat, perspective distortion becomes more of a factor (Figure 31B). If possible, place a lead ruler made for x-radiography on the film together with the subject being imaged. This will provide the most accurate scale, particularly for digital images. A stainless plate cut to a known length can also be used to provide scale reference.

FIGURE 28: ON THIS NAIL THE DIVISION BETWEEN THE CORE METAL AND THE CORROSION CRUST IS CLEARLY DEFINED; THAT IS WHERE MEASUREMENTS SHOULD BE TAKEN.

FIGURE 29: THIS NAIL IS ALMOST COMPLETELY MINERALIZED, BUT THE ORIGINAL SURFACE IS STILL DISCERNABLE AS A BRIGHT LINE THAT MAKES ACCURATE MEASUREMENTS POSSIBLE.



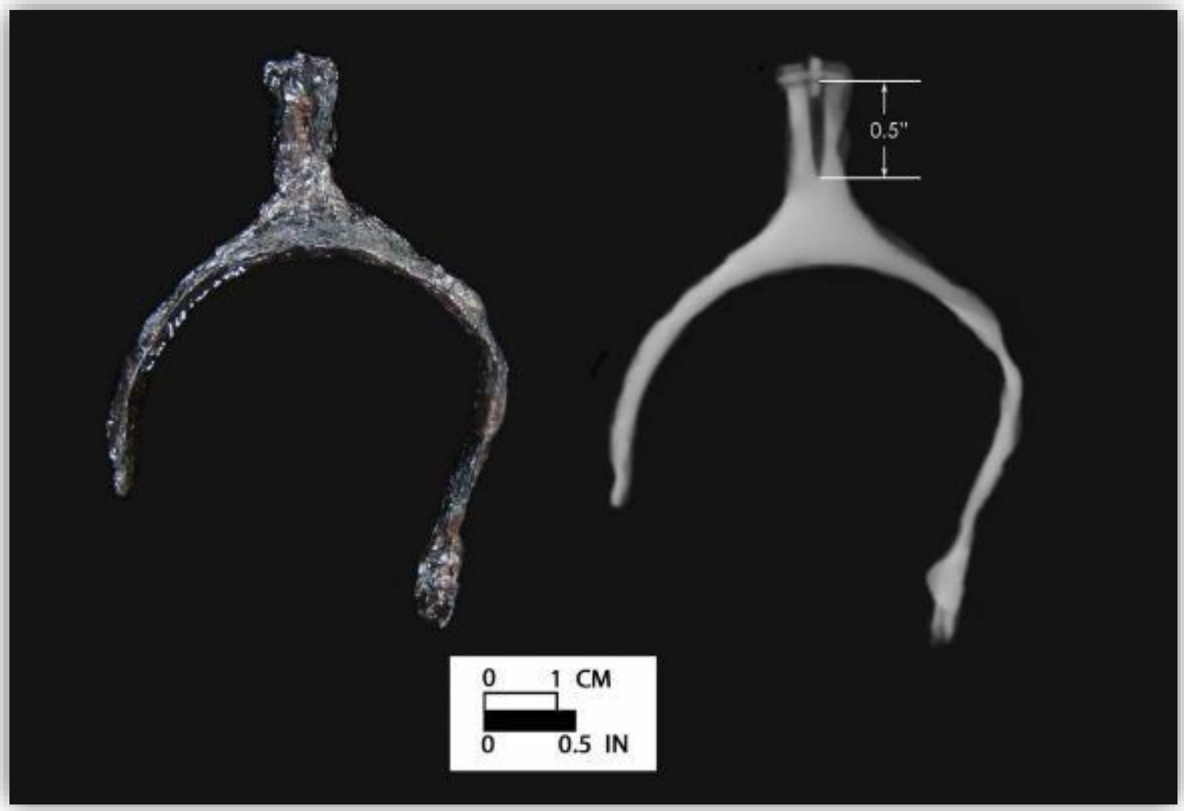


FIGURE 30: EVEN AFTER CONSERVATION TREATMENT, THE DETAILS OF THE ROWEL BOX ON THIS SPUR ARE OBSCURED BY THE REMAINS OF CORROSION. THE X-RAY OFFERS A CLEAR VIEW OF THE ROWEL BOX, ALLOWING PRECISE MEASUREMENT.

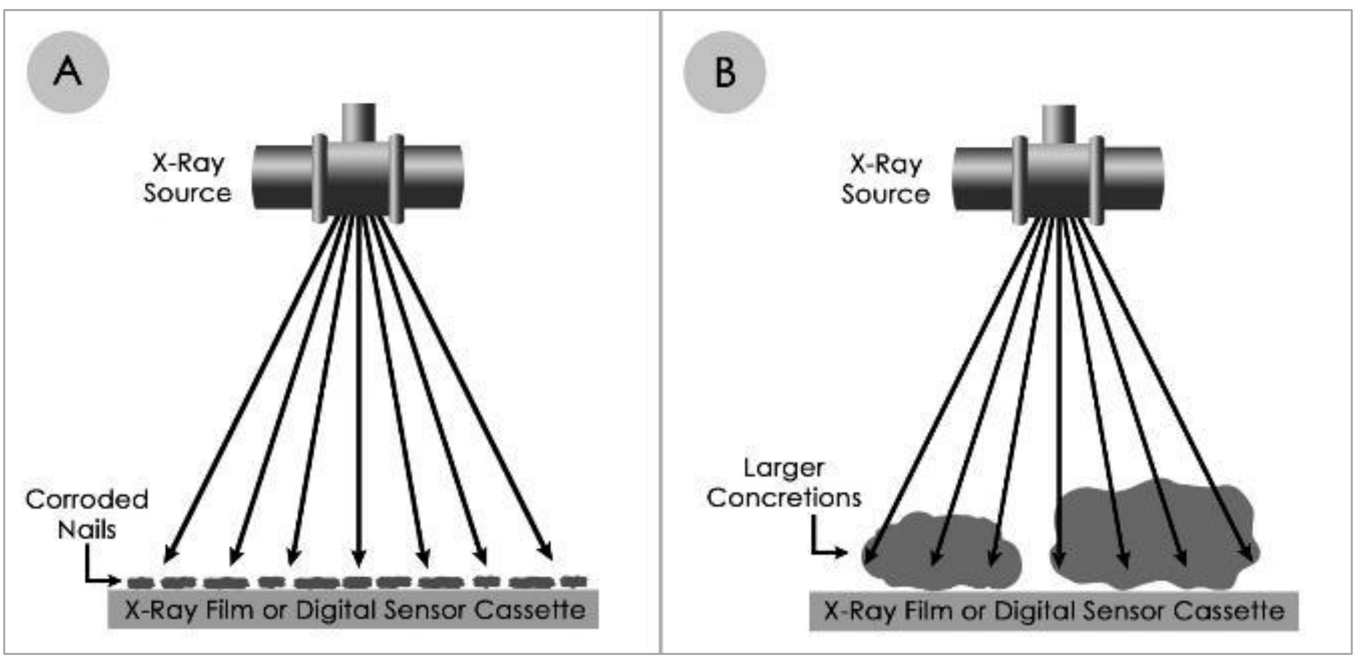


FIGURE 31: RELATIVELY FLAT OBJECTS LIKE CORRODED NAILS ARE REPRESENTED AT A 1:1 SCALE IN X-RAY IMAGES (A), BUT LARGER OBJECTS THAT DO NOT LIE RELATIVELY FLAT EXPERIENCE PERSPECTIVE DISTORTION (B). THIS DISTORTION IS DUE TO THE CONE SHAPE OF THE X-RAYS AS THEY DISSIPATE FROM THE SOURCE, WHICH CREATES AN EFFECT SIMILAR TO THE ENLARGED IMAGE OF SHADOW PUPPETS ON A WALL.

CHECKING FOR LOADED WEAPONS

X-radiography is a safe method for determining whether firearms and ordnance pose a risk of detonation. While gunpowder itself is not reliably visible on an x-ray, there are other ways to check for a potentially live weapon by knowing what materials to look for. Historic firearms typically have an iron barrel or chamber and lead projectiles. Metal cartridge cases, if used, are copper alloy (Figure 32). Due to the varying densities of these materials, they can be identified in an x-ray image. The presence of a lead bullet is a good indication that the propellant is still present, and the weapon should be neutralized by qualified professionals (Figure 33).

FIGURE 32: THIS PISTOL FROM DEADWOOD, SOUTH DAKOTA WAS LOADED WITH SPENT COPPER ALLOY CARTRIDGES, BUT NOT LIVE AMMUNITION.

COURTESY OF THE CITY OF DEADWOOD ARCHIVES

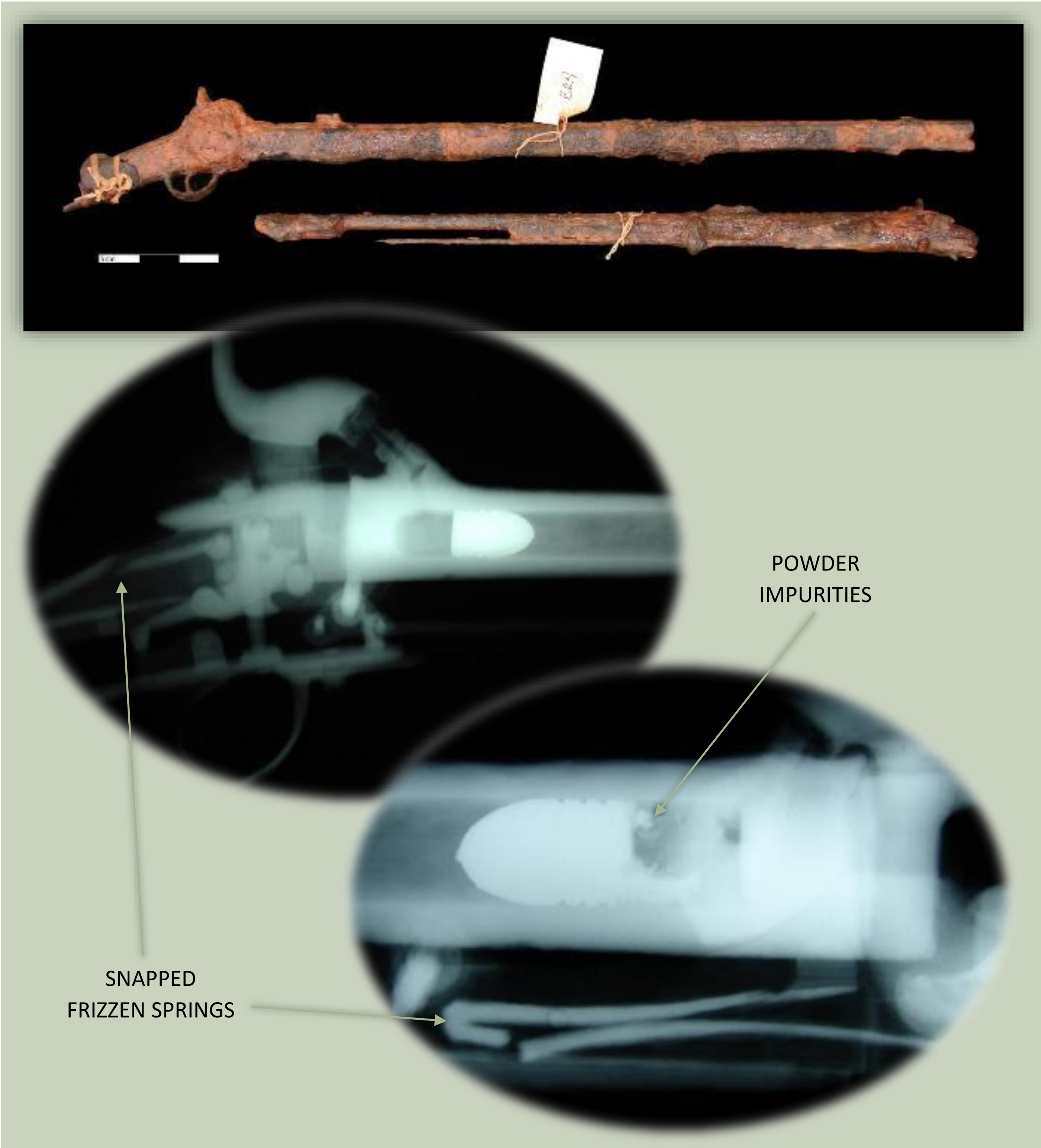


FIGURE 33: WHEN THE MAC LAB TREATED A GROUP OF CIVIL WAR MUSKETS THAT WERE HASTILY DISCARDED DURING A UNION RETREAT IN THE 2ND BATTLE OF BULL RUN, X-RAYS NOT ONLY REVEALED THAT THE MUSKETS WERE STILL LOADED, THEY ALSO SHOWED DETAILS LIKE SNAPPED FRIZZEN SPRINGS, COMPACTED SHOT, AND DOUBLE CHARGES THAT MAY EXPLAIN WHY THE WEAPONS MISFIRED AND BECAME A BURDEN TO THE RETREATING SOLDIERS. THE POWDER CHARGE IN ONE OF THE MUSKETS CONTAINED IMPURITIES THAT WERE DENSE ENOUGH TO SHOW ON THE X-RAY IMAGE.

COURTESY OF MANASSAS BATTLEFIELD TRUST

X-radiography can reveal the internal cavity containing the charge for explosive weapons such as bombs, shells, grenades, mines, etc. (Figure 34). It is sometimes possible to view the charge if the powder has dense inclusions (See Figure 33), but the technician is primarily looking for the presence or absence of the plug/fuse which may be obscured by corrosion. If the plug is still in place, qualified professionals should be contacted to neutralize the object.

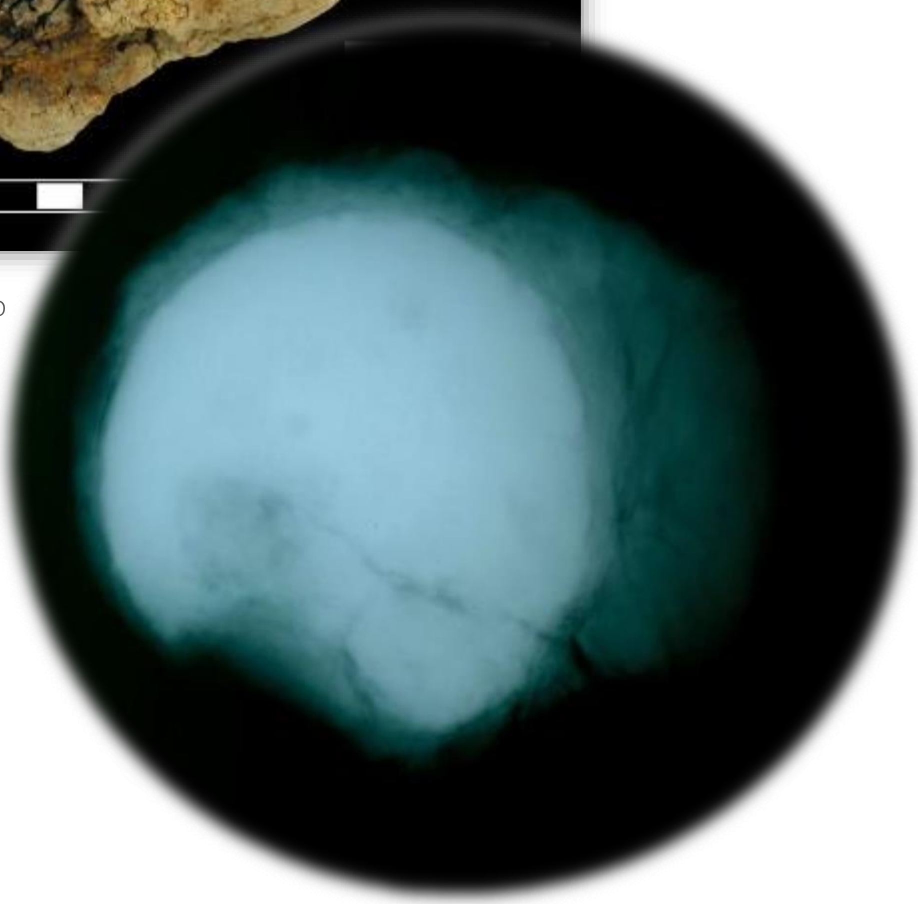


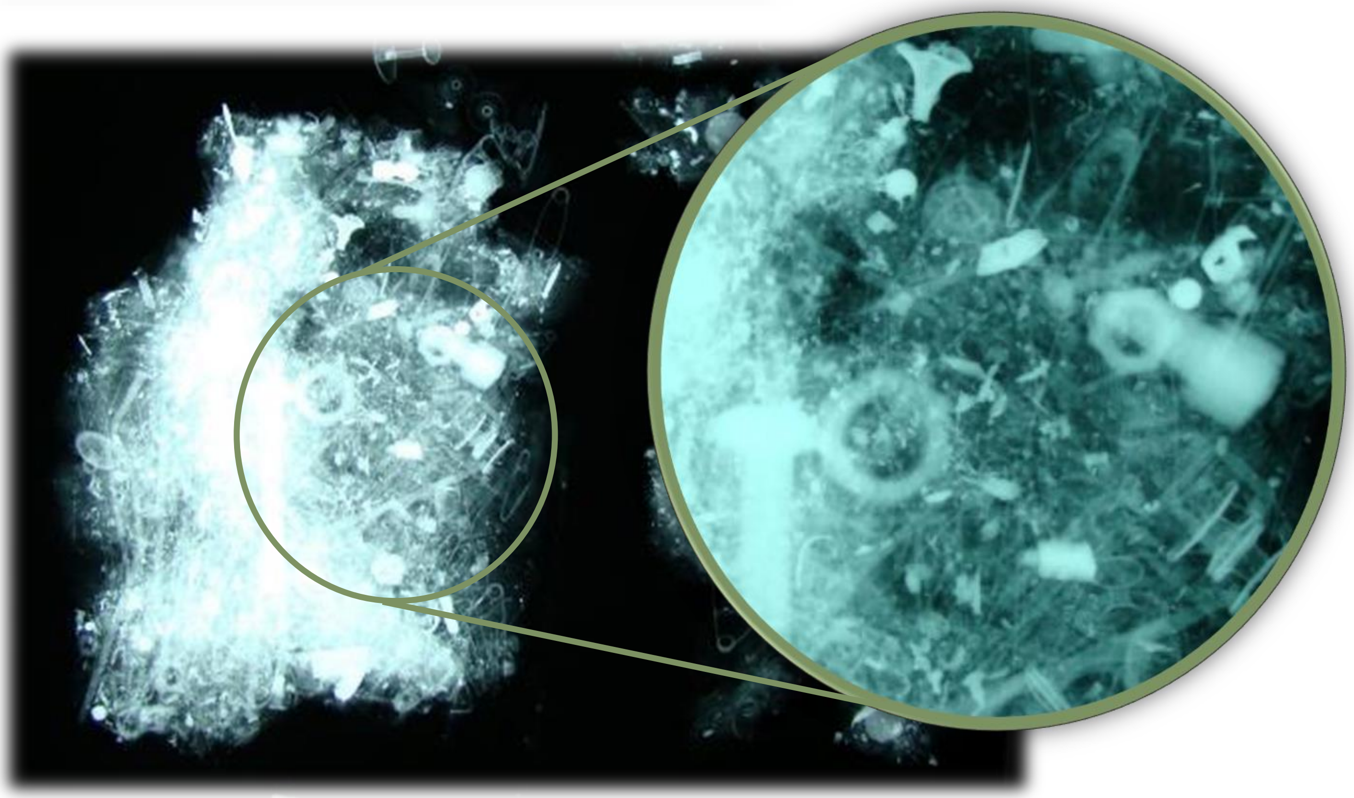
Figure 34: This heavily corroded grenade was recovered with its plug still in place, but X-rays showed that cracks and other damage to the shell had fully compromised the powder charge and there was no risk of detonation.

Courtesy of Delaware Division of Historical & Cultural Affairs

VIRTUAL "EXCAVATION" OF ARTIFACTS DEPOSITED TOGETHER

As corrosion forms it can produce crusts that trap soil and other materials from the surrounding environment. Sometimes this can preserve evidence of organics, like the wood around nails or cloth near buttons, but usually it is a source of frustration for archaeologists because it can hide the identity of the artifact within the crust. Corrosion can also trap other artifacts. When artifacts are deposited together, it can be desirable to keep them that way, since this offers information about artifact associations and deposition. In such cases, x-rays offer a method for seeing into the concretions without separating them (Figure 35).

FIGURE 35: SEVERAL SEWER PIPES FROM AN AREA OF BALTIMORE THAT WAS THE HOME TO A LAUNDERING BUSINESS IN THE EARLY 20TH CENTURY WERE CLOGGED WITH CORRODED NAILS, PINS, BUTTONS, BOLTS, AND OTHER DEBRIS. X-RAYS OFFER A LOOK INSIDE THE CONCRETION WITHOUT DISMANTLING IT. UNFORTUNATELY THE LOW-DENSITY ARTIFACTS TRAPPED IN THE CORROSION ARE NOT VISIBLE ON THE X-RAY. FOR EXAMPLE, SHELL BUTTONS ARE VISIBLE ON THE SURFACE OF THE CONCRETION, BUT NONE ARE VISIBLE ON THE X-RAY. NO DOUBT THERE ARE OTHER ORGANICS THAT EXIST WITHIN THE CONCRETION EVEN THOUGH THEY ARE UNINTENTIONALLY "ERASED" IN THE X-RAY IMAGE.



PART II: DOCUMENTATION FOR CATALOGING AND SAMPLING

This section offers recommendations and examples of how to add x-radiography to a project workflow, specifically for projects where x-rays will be used as part of a responsible sampling strategy. If included in project planning from the beginning, this process may result in cost savings when it comes time to pay curation repository fees.

PLANNING AND BUDGETING

X-rays should be considered during the project planning phase. The following

1. DETERMINE WHETHER THE PROJECT SHOULD BUDGET FOR X-RADIOGRAPHY
   Systematic documentary x-radiography is most useful for post-contact sites excavated at the Phase II or Phase III level (Table 2). These are the projects most likely to yield corroded blobs that are not recognizable to the naked eye and bulk metals that are rarely a priority for conservation treatment (i.e. nails, tin cans, flat ferrous straps, etc.). Budgeting for systematic x-radiography for surveys/Phase I projects or projects targeting precontact sites is not recommended. X-radiography may not be necessary for sites where the Phase I has shown that there is good iron preservation and little corrosion to obscure artifacts. Such collections may be sufficiently documented with photography instead.

2. CHECK WITH STAKEHOLDERS ABOUT THE SAMPLING STRATEGY
   Using x-radiography for documenting and sampling metals is not yet standard practice, so check with the various stakeholders in advance of a project to make sure all are on board. Stakeholders might include SHPO offices reviewing the project, the repository that will be accepting the collection, and the collection's owner, which may be a private landowner, a federal agency, etc.

3. ESTIMATE THE NUMBER OF BOXES OF METALS EXPECTED
   Most archaeology labs employ a formula to predict the number of boxes of artifacts expected before fieldwork begins so that lab work and curation fees can be included in the budget. This step is a variation that considers what portion of that estimate is likely to be metal.

   It is the MAC Lab's experience that the later the site the more metal there is likely to be. 17th-century sites tend to be 5-10% metal, 18th-century sites are closer to 10-20% metal, and 19th- to 20th-century sites tend to be higher still at 20-30% metal. These percentages probably vary by region and certainly vary by site type (i.e. estimate higher for an iron furnace, lower for a ceramic kiln). Since x-radiography is generally best for Phase II or III level excavations only, use the Phase I artifacts to help with estimates.

4. IDENTIFY THE X-RADIOGRAPHY PROVIDER
   In order to budget for x-rays, identify where you're getting them and how much they charge per film or plate. Find out the size of plate they use to estimate how many artifacts will fit. Also decide with the provider who will lay out the artifacts and label the resulting images. For best results, the person who will be doing the cataloging should be involved in this process (See below). It may also represent cost savings to have someone from the artifact processing lab do this work instead of the x-ray technician.

PRO TIP: BUDGETING

If you're trying to keep the budget down, don't assume that *less* x-radiography funding will necessarily represent cost savings. If you get permission to discard bulk metals once they have been properly documented, that can represent cost savings on curation repository fees.

TABLE 2: THIS IS A QUICK CHECKLIST TO DETERMINE IF X-RADIOGRAPHY IS APPROPRIATE FOR AN ARCHAEOLOGICAL PROJECT AS PART OF A SYSTEMATIC SAMPLING STRATEGY.

X-radiography is recommended if the answer is YES to ALL of the following:	YES	NO
Is the project equivalent to a Phase II or III excavation?	❑	❑
Is the project focused on a post-contact site likely to yield bulk metals (i.e. nails)?	❑	❑
Is metal preservation poor, with corrosion preventing artifact identification? (Check Phase I artifacts to evaluate preservation conditions)	❑	❑
Do all stakeholders agree to the documentation and sampling of bulk metals?	❑	❑

5. DO THE MATH

   Estimates should be based on the cost per film and the percentage of the collection expected to be metal. The math comes in when figuring out how many films or plates are needed to cover the metal artifacts predicted.

   At the MAC Lab, the 14” x 17” plates we use are similar in size to our standard box lid. We use 12” x 15” x 10” record boxes for curation and have found that full boxes of metal that are mostly nails take 10 to 12 x-ray plates. This makes sense because at 10” high our boxes could theoretically contain 10 or more stacked trays of artifacts laid out flat as long as the artifacts are small. Not all metal boxes can be so neatly sectioned since nails are not the only metals found (Figure 36). Not enough projects have adopted systematic x-ray to allow us to fully test our estimates, but **we currently advise planning for at least eight plates per box of metals** (about 2,000 square inches of film space). This should allow x-radiography of a good sample of the metals, if not all of them.

   Alternately, work with the project stakeholders to settle on a sampling strategy and calculate the number of plates needed accordingly. Some repositories may allow discard even if a representative sample of nails were documented through x-radiography (González and Salvato 2019).

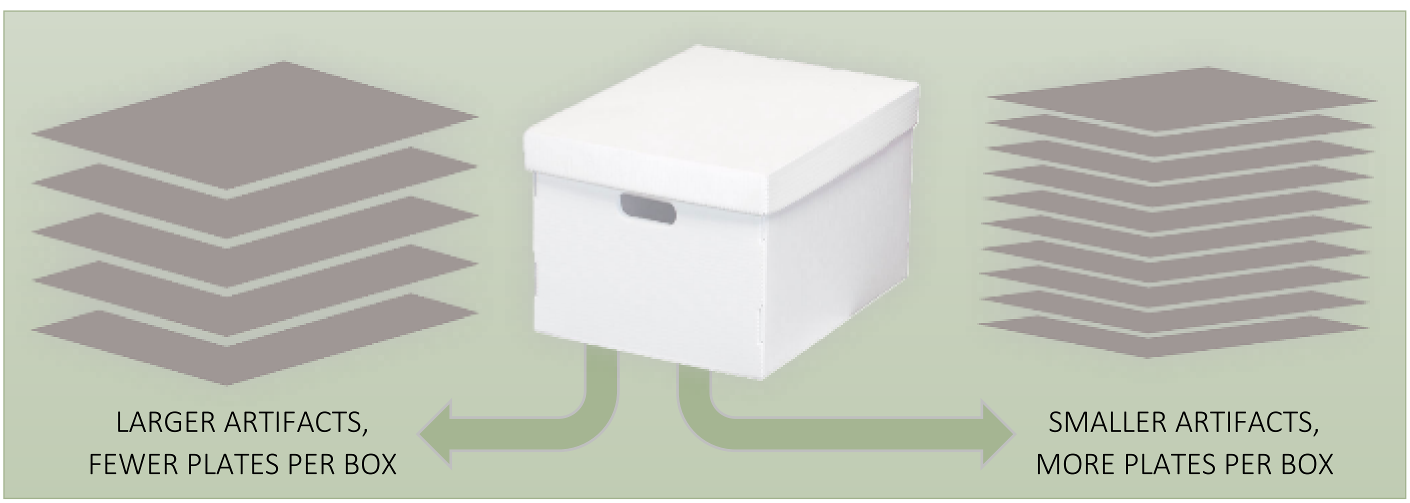


FIGURE 36: THE NUMBER OF PLATES NEEDED TO X-RAY A BOX OF METALS DEPENDS ON THE SIZE OF THE ARTIFACTS. A BOX OF NAILS MAY NEED 10 OR MORE PLATES BECAUSE SO MANY CAN FIT IN A BOX. BOXES WITH LARGER ARTIFACTS NEED FEWER PLATES. SINCE THERE IS NO WAY TO KNOW WHAT WILL BE FOUND, WE RECOMMEND BUDGETING FOR EIGHT PLATES PER BOX.

ARTIFACT PROCESSING: ADDING X-RADIOGRAPHY TO THE WORKFLOW IN THE LAB

When using x-rays for sampling and discard, regular lab procedures may warrant some alteration. The following is a list of things to consider when adding x-radiography and sampling to the lab workflow.

6. WASHING? DON'T BOTHER!
   If you have planned a project with systematic x-radiography for sampling purposes, then dry brushing corroded metal need not be part of the lab workflow until after x-radiography. Dirt does not interfere with x-ray images and if the plan is to document and discard many of the metals, cleaning them will have been a wasted effort. Anything prioritized for conservation can stay dirty, too; the conservators will take care of it. Only the artifacts considered worthy of retention but not treatment then warrant some cleaning prior to curation.

7. BAGGING? GO BIGGER!
   The usual rule is to use the smallest bag feasible to hold the artifacts without causing damage, but for x-rays it is helpful to use a bag that is just big enough to allow all of the artifacts within to lay flat in the bag without overlapping each other (Figure 37). This will allow the bag to be placed on the x-ray cassette without removing the artifacts. Placing full bags on an x-ray with the artifacts overlapping results in jumbled images and will cost a lot of time during the cataloging process (Figure 38).

FIGURE 37: USING BAGS THAT ARE BIG ENOUGH TO ALLOW THE ARTIFACTS TO SPREAD NEARLY FLAT RESULTS IN AN X-RAY WITH MINIMAL ARTIFACT OVERLAP. BAGS THAT ARE TOO BIG MAY NOT FIT WELL. IN THIS CASE THE METALS FOR LOT 85 WERE SEPARATED INTO FIVE BAGS THAT FIT WELL ON THE X-RAY PLATE.

COURTESY NAVAL DISTRICT WASHINGTON, NAVAL AIR STATION PATUXENT RIVER

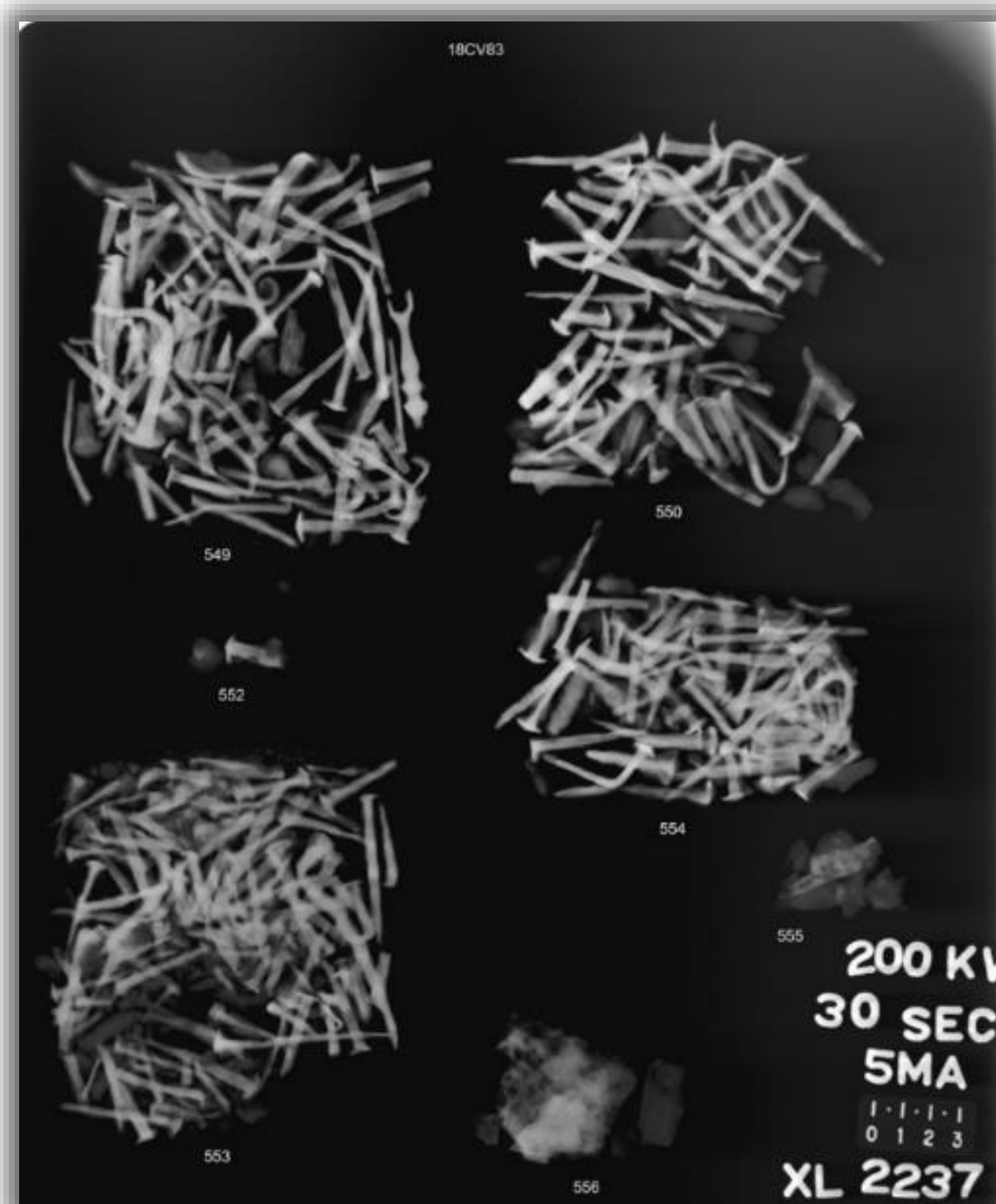


FIGURE 38: X-RAYING NAILS IN VERY FULL BAGS RESULTS IN OVERLAPPING IMAGES THAT ARE DIFFICULT TO USE FOR CATALOGING PURPOSES. THE NAILS ARE DOCUMENTED, BUT THE OVERLAP MAKES COUNTING AND MEASURING THE NAILS MUCH LESS FEASIBLE. SUCH IMAGES CAN HELP IDENTIFY ARTIFACTS THAT SHOULD NOT HAVE BEEN BAGGED WITH THE NAILS, BUT THEY ARE DIFFICULT TO CATALOG. IN THIS IMAGE THE LOT 549 NAIL BAG YIELDED A TWO-TINED FORK FRAGMENT AND THE LOT 550 NAIL BAG CONTAINED A TRAPEZOIDAL BUCKLE FRAME. CAN YOU SPOT THEM?

8. LABELING
   Labeling bags of metals slated for x-ray is the same as usual. Make sure the provenience is clear on the bag and on an interior tag for back-up.

9. CATALOGING: NOT YET!
   Usually cataloging happens sometime after cleaning and the preliminary bagging and labeling, but when dealing with heavily corroded metals it is important to catalog AFTER x-radiography. It takes a lot longer to edit existing catalogs than it does to catalog from an x-ray in the first place (See González and Salvato 2019).

10. X-RADIOGRAPHY

After bagging and labeling it is time to x-ray the metals. For best results, have someone who will be involved in cataloging also be present to lay out the artifacts and document the process. You will be happiest with the results if you make sure the resulting x-ray images are the best possible fit with *your* lab and catalog systems.

a. Lay out the artifacts to be x-rayed on a non-metal tray or box lid that mimics the size of the x-ray film or digital sensor cassette to be used (Figure 39). This allows you to take your time with the layout and keep the tray intact while the x-ray is processed.
b. Be sure to keep control over provenience, either by leaving the artifacts in the bag with the labeled side up (while still laying them flat so they don't overlap), or by using separators such as smaller boxes or trays. If removing artifacts from bags, keep paper labels with the artifacts and have them face up (Figure 40). If you end up folding or overlapping bags to fit more artifacts on the plate and this covers up the bag label, place paper tags that will be visible in a photo of your finished layout.
c. If using lead numbers and letters as labels, add them to the layout. Also add a lead ruler for scale if one is available.
d. **Take a picture of your finished layout**. This is important for several reasons, but the main one is that photos can help match the right bags or corroded blobs to the x-ray. "Match the blob" is not a very fun game and a waste of time when taking a quick picture will help. Questions may come up later that you don't think to check at the time, and the photo can be a useful reference. Plus, we all know that labeling mistakes happen. Having a photo of the layout to put side-by-side with the x-ray creates a source you can cross-reference to make sure everything is labeled correctly.
e. Take the x-rays and view the images. Again, results tend to be best if you are present for the x-rays in case you want a different angle or setting to see something more clearly.
f. If possible, view the resulting x-ray images with the artifact layout still intact. This maximizes the chances that you can easily find a corrosion blob that turned out to be something conservation worthy. Separate out any special items and label them *before* you put everything away.
g. Rename digital files of the layout photo and x-ray to indicate their connection. For example, at the MAC Lab every x-ray gets an X-ray Log number, such as XL2113. We include this number in the x-ray image file name and the layout photo file name.

11. CATALOGING

Now you can catalog corroded metals using the x-ray as a reference. For best results, have both the x-ray and the corroded artifact when cataloging so that you can describe any three-dimensional characteristics that might be hard to understand on the x-ray.

Bags or No Bags?

One of the decisions to make when doing x-radiography is whether to leave the artifacts in the bag or lay them out. This is a case by case judgment call, but here are some things to consider:

NO BAGS

PROS:

- The best x-rays result when you lay out the artifacts individually with no overlap (Figure 39).
- Careful layout maximizes the plate space used so money isn't wasted on big blank areas.
- Removal from bags makes for the best documentary photos; the photo of the artifact can be easily matched to its x-ray.
- It's easy to grab the blobs that turned out to be something interesting on the x-ray; no digging around in a bag of blobs looking for the right one.

CONS:

- It can take a lot of time depending on how neatly you want to do your layouts. Lining everything up in neat rows takes a lot longer than simply dumping out the bag in a tray and spreading the contents out to avoid overlap (Figure 40), but both take longer than just putting the bag on the film.
- You need smaller boxes or trays to safely control for provenience.
- It results in handling that may cause damage, especially for collections that have been sitting for a while.
- It's messy!

KEEPING THE BAGS

PROS:

- Placing bags on the plate without removing artifacts is faster than laying out each artifact in nice neat rows, and time is money.
- No chance of losing provenience information.
- Less mess!

CONS:

- X-rays of bagged artifacts often result in crowded or overlapping images that make it very hard to catalog and measure artifacts and label the x-rays to correlate with the catalogs (Figures 38).
- Photographs of the layout are less useful as a cross-reference for artifacts in an x-ray when bags are present. Usually the bags are too dirty or have too much glare to allow a visual of the objects within.
- When leaving artifacts in the bags it is more difficult to find the blob that the x-ray has revealed to be something worth conserving.

SOME COMPROMISES

- Sometimes you can avoid the pitfalls of keeping artifacts in the bags just by using a bigger bag than usual and carefully flattening the bag on the film to prevent overlap. This works best for really crusty "Cheeto" nails that will roll around next to each other without getting tangled up (Figure 37).
- If you have a large lot of metal, avoid frustrating "find the blob" scenarios by breaking the lot up into several bags instead of one large one to make it easier to locate things (Figure 37).
- Be prepared by asking what size plate your provider uses and choose your bag sizes accordingly to avoid unused space.
- Adopt a combination of approaches. For example, keep the bags for small batches of artifacts but lay out larger lots that create more of a cataloging challenge (Figure 41).

Figure 40: Laying out artifacts for x-radiography takes time, but the resulting X-ray images are the easiest to catalog, especially if you leave room between nails to add labels.

Figure 39: If smaller boxes or trays are available, it doesn't take much time to remove artifacts from bags and spread them out to prevent overlap. Visibility is good on the resulting x-ray, though the x-ray is a bit more difficult to catalog and label when artifacts are not more carefully lined up.

FIGURE 41 : THERE WAS LITTLE POINT IN REMOVING NAILS FROM THE SMALL BAGS FOR THIS LAYOUT, BUT FOR THE LARGER LOT AT THE BOTTOM IT WAS WORTH THE EFFORT TO LAY THE ARTIFACTS OUT FOR THE BEST VISIBILITY.

12. X-RAY LABELING WITH ID INFORMATION

Documenting catalog IDs is typically accomplished by strategic bagging, labeling, and numbering of artifacts, but it is a bit different when the x-ray serves as the basis of the ID. There are many possible approaches, so choose what works best with your system. Here are a few options for labeling x-rays with catalog information:

a. Go low-tech. Print out the x-ray images and label the printouts using a pen. Advantage: Easy and fast. Disadvantage: Prints may not be the best quality and you need good small handwriting. You may also need white ink unless you convert the image to the negative in a photo-editing software first (Figure 42).
b. Add call-out boxes or other labels to digital files (Figure 43). Advantage: Relatively easy and fast and can be done in most programs (Word, Power Point, Photoshop, etc.). Disadvantage: May get crowded on a full film, and this requires the extra step of converting the resulting images to a stable format suitable for long-term archiving.
c. Use photo editing software to rearrange the x-ray image by catalog grouping (Figure 44) or copy and paste artifacts from the x-ray image to a supplemental catalog sheet. Advantage: Thorough and easier to read. Disadvantage: Time consuming and requires photo editing software and skills.
d. Adopt a combination of approaches. For example, you might want to create supplemental catalog sheets for whole measurable diagnostic nails only, use call-out labels for recognizable fragments, and make a note that anything unlabeled on the x-ray remains unidentified. Advantage: You do what's best for your project. Disadvantage: The different techniques may be confusing for others to follow unless you record the process thoroughly in the lab records.

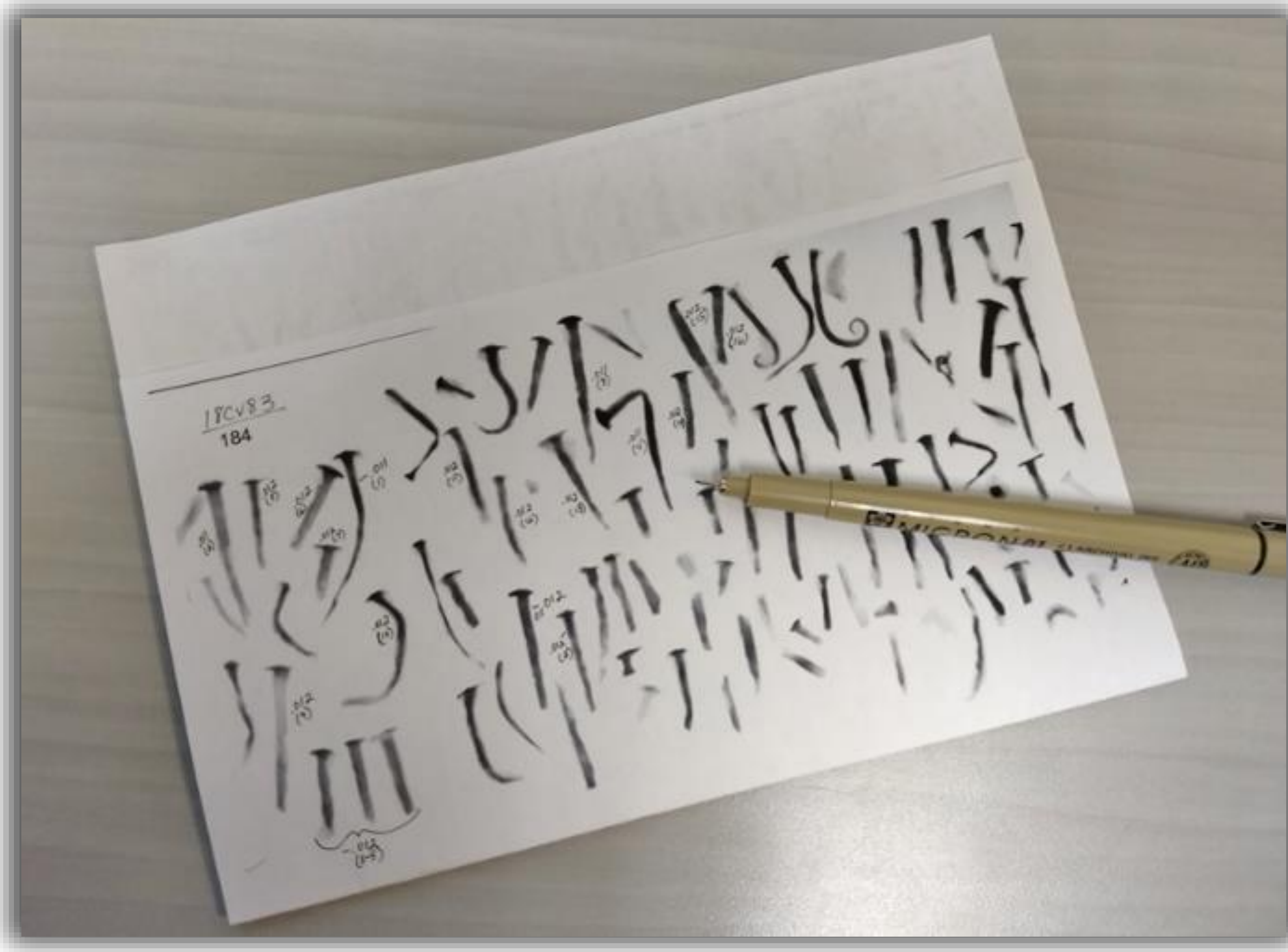


FIGURE 42: ONE METHOD FOR LABELING X-RAYS BY CATALOG BATCHES IS TO PRINT THEM OUT. PRINTING AN INVERSE OF THE X-RAY IMAGE ALLOWS FOR PLENTY OF WHITE SPACE TO ADD CATALOG DESIGNATIONS AND COUNTS. YOU CAN EVEN CUT PRINTOUTS UP AND SORT THE ARTIFACTS INTO STACKS TO MAKE COUNTING EASIER. FOR BEST RESULTS THOUGH, TAPE THOSE SORTED STACKS TO A PIECE OF PAPER AND MAKE A NEW (LABELED) COPY TO KEEP WITH THE PROJECT DOCUMENTATION.

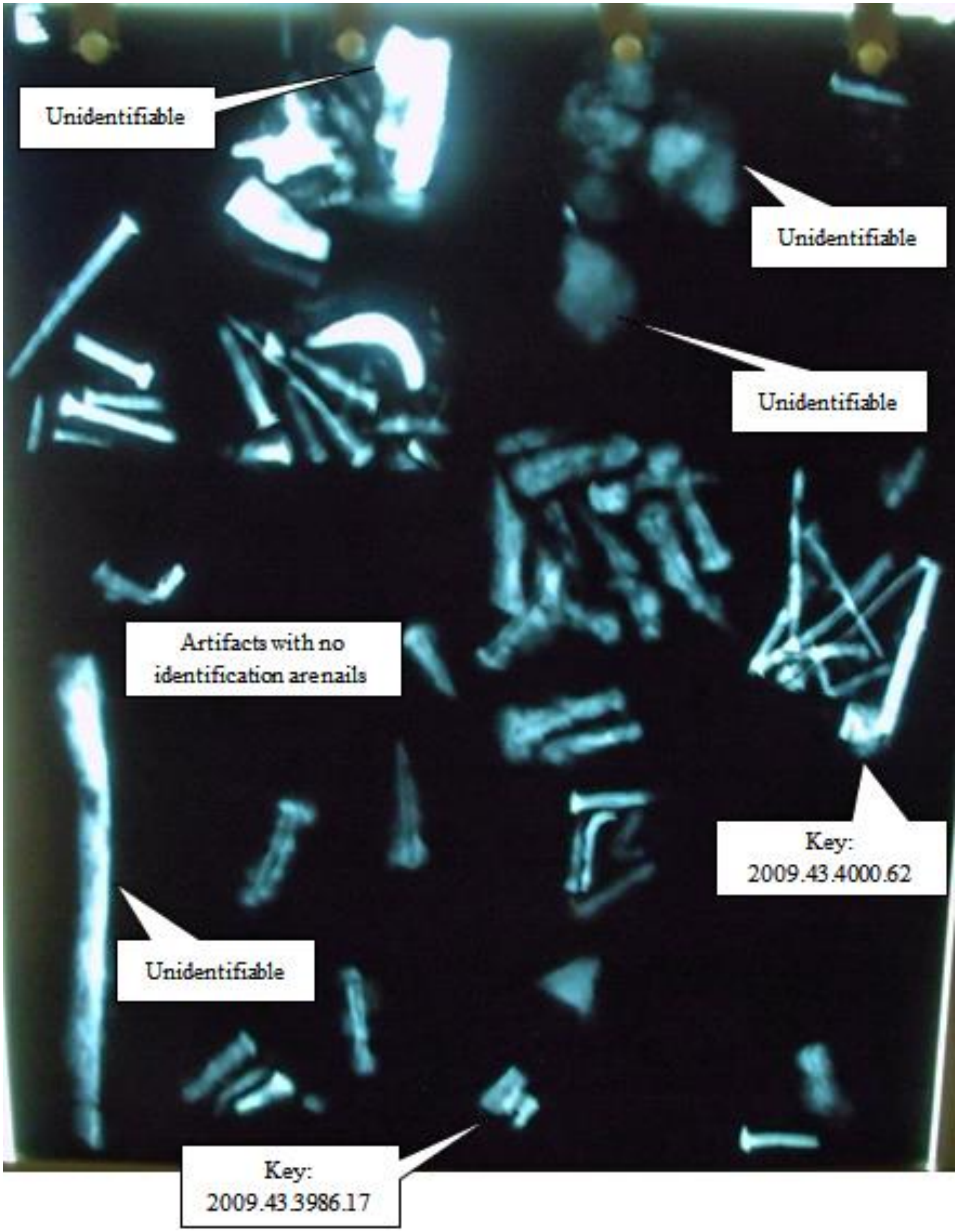
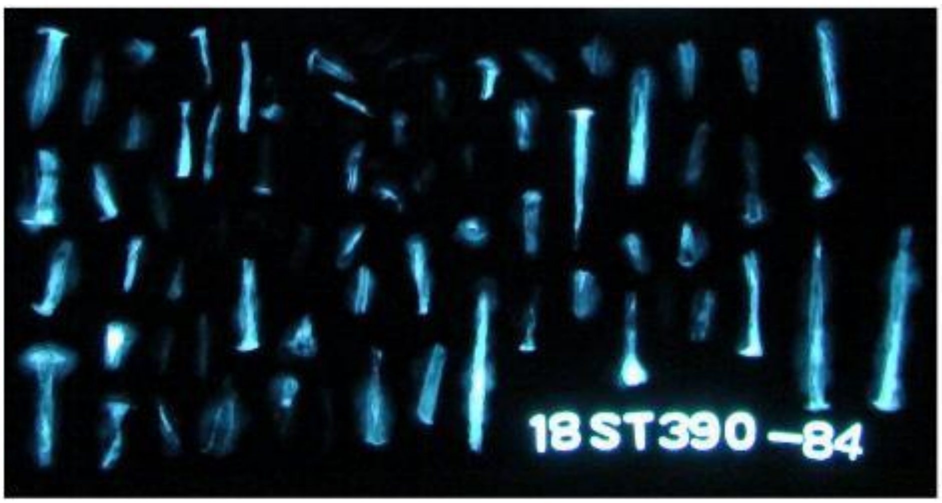


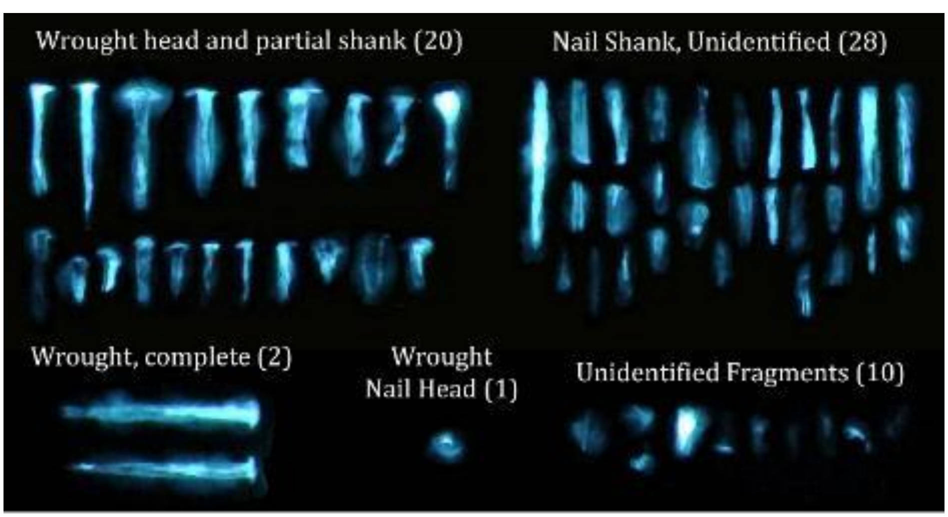
FIGURE 43: THIS X-RAY WAS LABELED USING CALL-OUT BOXES THAT ARE AN OPTION IN PROGRAMS LIKE WORD AND POWER POINT. THE TECHNIQUE IS EASY AND FAST, BUT BE SURE TO SAVE THE LABELED X-RAYS IN A STABLE FORMAT, SUCH AS PDF, JPG, OR TIFF TO AVOID LOSS OF FORMATTING AS NEW VERSIONS OF SOFTWARE ARE INTRODUCED.

PHOTO BY KERRY GONZÀLEZ, COURTESY OF THE DELAWARE DEPT. OF TRANSPORTATION AND THE FEDERAL HIGHWAY ADMINISTRATION

65 Corroded iron “cheeto” nails went in for X-radiography.



61 Fragments had enough core metal remaining to show on the X-ray.



23 wrought nails were revealed, making 38% of the artifacts diagnostic.

FIGURE 44: THIS SEQUENCE OF IMAGES SHOWS THE PROGRESSION FROM ARTIFACT PHOTO, TO X-RAY, TO ARTIFACTS GROUPED BY CATALOG BATCH. EDITING PHOTOS LIKE THIS IS TIME-CONSUMING, SO THIS APPROACH ONLY WORKS WELL IF YOU HAVE PLENTY OF TIME OR EAGER INTERNS OR VOLUNTEERS WHO LIKE TO EDIT PHOTOS.

13. SETTING PRIORITIES FOR CONSERVATION, CURATION, AND DISCARD

    Once the x-rays have been taken and all the artifacts are catalogued, it is time to make decisions.

    a. If you haven't done so already, this is the time to choose the high-priority objects that will be receiving conservation treatment.
    b. For corroded metals that will be retained without conservation, clean and package them according to the requirements of the receiving repository.
    c. Implement the sampling and discard strategy you planned for. You may want to touch base with the stakeholders again once you have identified the artifacts slated for discard to make sure that all concur before you throw them away.
    d. Make a note on the catalogs of any artifacts sent for treatment or discarded.

14. FINALIZE THE DOCUMENTATION

    Make sure that all the documentation accumulated through this process is included in the project records submitted to the repository. This should include a clean version of each x-ray, the photos of the x-ray layouts, annotated x-rays with labels that correlate to catalogs, etc.

PART III: X-RADIOGRAPHY AT THE MAC LAB

FIGURE 45: INTERIOR OF THE MAC LAB'S X-RADIOGRAPHY ROOM.

EQUIPMENT

The MAC Lab utilizes a 12' x 12' x-radiography room with an adjustable overhead x-ray source (Figure 45). The entrance to this space is limited by a 4'4" entryway and the maximum recommended length for an object is approximately 10 feet. The x-ray source has a max setting of 320kV and 6.5mA.

Rather than traditional X-ray film, the MAC Lab uses computed radiography (CR) cassettes to capture X-ray images (Figure 46). Hard cassettes are standard, but the MAC Lab also has soft cassettes that can be wrapped to fit the curvature of larger objects should that be needed. The cassettes measure 14" x 17" including a ¼" margin.

Once the CR cassette is processed, the data is converted into a digital image. Depending on the degree of detail required, the software allows for an adjustable range of image resolutions from 50 – 200 dpi (dots per inch). There are several file types available for export. JPEG files are the smallest format available and are recommended when sharing files via email. TIFF files are larger format with variable resolution that is recommended for publishing purposes. DICONDE files are the largest and contain the greatest quantity of meta data that allows for the manipulation of the X-ray image using open source software such as AMIDE and JiveX.

For the larger image files, we recommend bringing a CD-R, DVD-R or flash drive.

FIGURE 46: CONSERVATOR FRANCIS LUKEZIC PREPARES ONE OF THE COMPUTED RADIOGRAPHY (CR) CASSETTES FOR PROCESSING.

PERSONNEL

Two staff members are required to process x-ray images to meet health and safety requirements for the use of radiographic materials. It is also useful in the safe transport of artifacts and ensuring proper documentation. Conservators are outfitted with dosimetry equipment that monitors both personal exposures and single event exposures to radiation. Anyone assisting in the processing of the x-ray materials will also be outfitted with a personal dosimeter.

THE PROCESS

The MAC Lab strongly encourages that the curator/lab manager/principle investigator be present during the x-raying process if possible. While conservation staff are able to x-ray collections unassisted, it is beneficial to the process if collections staff are available to communicate their analytical requirements directly and provide feedback to the x-ray operator. It can also be difficult to read x-ray images if one is unaccustomed to them. MAC Lab staff are available to assist with interpretation and identification of the material.

If a personal visit is not possible, artifacts can be delivered to the MAC Lab, where staff will organize the material for x-radiography for an additional fee.

Once the artifacts are laid out on a cassette for image capture, there are several methods available to ensure that objects are documented and identified correctly. While film x-rays are produced as a 1:1 scale representation of the object imaged, digital x-rays are most effective when a lead scale/ruler is included in the layout. Metal wires can be used to visually denote different contexts. Lead numbers, letters and arrows are available to annotate the image. It is also possible to annotate the image digitally postproduction. The image created can be digitally inverted so that the objects appear black on a white background for greater ease of printing and later annotation.

The MAC Lab uses card trays to arrange the objects, which are then placed on the surface of the cassette during the plate's exposure (Figure 47). The tray of objects is then removed so that the image can be processed while the orientation of the artifacts remains undisturbed (Figure 48). This allows for repeat exposures should that be required. Most importantly, it allows for an object viewed on the X-ray to be readily located on the layout of the tray.

FIGURE 48: CONSERVATORS HEATHER RARDIN AND FRANCIS LUKEZIC SLIDE A CR CASSETTE UNDER A PREPARED TRAY PRIOR TO X-RADIOGRAPHY.

FIGURE 47: LEAVING THE LAYOUT TRAY INTACT AS X-RAYS ARE PROCESSED ALLOWS EASY COMPARISON OF THE X-RAY IMAGE TO ARTIFACTS.

PRICING

It takes approximately one hour to process four x-ray images, from the initial layout of objects to final image annotation. As labor makes up the bulk of our x-radiography fees, our pricing is scaled in batches of four images. Should there be lesser quantity of material, prorating is available (Table 3). Where large collections require x-radiography, bulk rates may be possible. Please contact the Head Conservator to discuss your specific needs, 410-586-8577.

TABLE 3: COSTS FOR UP TO FOUR X-RAY PLATES, INCLUDING RATES WHERE THE CLIENT DOES THE LAYOUT (X-RAY ONLY) VERSUS RATES THAT INCLUDE LABOR TO DO THE LAYOUT. FOR MORE THAN FOUR PLATES, ADDITIONAL LABOR HOURS APPLY, SO THE RATE SCALE RESTARTS. FOR EXAMPLE, FOR FIVE X-RAYS ADD THE COST OF FOUR X-RAYS AND ONE X-RAY ($270+$195=$465).

# of x-ray images	MAC Lab fees, x-rays only	MAC Lab fees, x-rays plus layout labor
1	$240	$275
2	$265	$300
3	$290	$325
4	$315	$350

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