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WORKING WITH A COLLECTION OF RADIOACTIVE AIRCRAFT INSTRUMENTS

SHARON NORQUEST, AMELIA KILE, AND DAVID PETERS

The Smithsonian National Air and Space Museum holds approximately 5,500 instruments that pertain to flight management, navigation, and engine and system performance. In fall 2013, a project was undertaken to outfit a large display case at the Steven F. Udvar-Hazy Center with 86 instruments from the collection. The display illustrates how the technology of instrumentation has advanced over the past 100 years as we progressed from the analog to the digital age.

Included in this collection are both unique prototypes and mass-produced gauges from civilian and military aircraft. Although the collection is vast, many of the instruments contain one common hazardous feature: radium paint. This glow-in-the-dark paint allowed pilots to fly at night and read the instruments while maintaining their night vision in a low-lit cockpit. Even though the paint no longer glows in the dark, the radium continues to emit measurable radiation. This paint presents the challenge of conserving, storing, and displaying a collection of radioactive objects in a museum.

Questions that arose and were addressed during the project included the following. What, if any, ideals must be compromised when dealing with a large collection that poses health hazards to the public and to staff? Is the workflow altered because of additional outside regulation, institution-wide requirements, and safety and health concerns?

A safe working environment for the staff and a safe display case for the public were established. As the Smithsonian National Air and Space Museum has a large collection of radioactive objects, the collection is licensed by the United States Nuclear Regulatory Commission. In addition to conservation work for the display, tasks were completed to meet the requirements of the Nuclear Regulatory Commission license. These tasks will be discussed and an explanation of equipment used to record radiation levels will be provided, as we developed a practical system for working with a radioactive collection.

KEYWORDS: Radioactive, Radium, Aircraft, Instruments, Health, Safety, NRC

1. INTRODUCTION

A vast collection of aircraft instruments are housed at the Smithsonian National Air and Space Museum (NASM). The term *aircraft instrument* pertains to many different devices. These devices aid with flight management, assist with navigational purposes, and indicate engine and system performance. This collection includes single instruments and entire panels of instruments that were removed from the cockpits of airplanes, helicopters, gliders, and airships. In fall 2013, a project was undertaken to outfit a large display case at the Steven F. Udvar-Hazy Center with 86 instruments from the collection. These objects were previously in storage, making this a great opportunity to share unseen objects with the public.

The display illustrates how the technology of instrumentation has advanced over the past 100 years, and NASM is fortunate to have unique prototypes of early models. World War I put new demands on aircraft, and now pilots were flying in adverse conditions out of necessity. These adverse conditions generated a scenario of flying at night or in inclement weather where previous methods of flying by sight were no longer possible. As flying at night became more routine, new methods of lighting a cockpit were developed, which included application of radium paint onto dials and switches. The use of radium paint decreased significantly after World War II.

Paint containing radium is a type of luminescent paint. This glow-in-the-dark paint allowed pilots to the read the instruments while maintaining their night vision in a low-lit cockpit (fig. 1). Approximately two-thirds of the instruments displayed in the case at NASM contain radium paint. Even though the paint no longer glows in the dark, the radium continues to emit measurable radiation. This paint presents the challenge of conserving, storing, and displaying a collection of radioactive objects in a museum. In preparation for and over the course of the project, procedures were established to provide a safe working environment for the staff and a safe display case for the public.

Fig. 1. This Mach meter is an instrument in the display case that contains radium paint. NASM, A19490053000. (Courtesy of Sharon Norquest)

2. RADIUM PAINT

Radium paint is composed of the radium isotope Ra-226, usually in the form of a radium salt such as radium sulfate, radium bromide, or radium chloride (Lind 1925). Radium sulfate was usually preferred, as it is less soluble than the other salts (Frame 2007). This radium salt is combined with a luminescent material and a paint binder. Historically the luminescent material was zinc sulfide (Jones and Day 1945). The energy from the radium interacts with the luminescent materials, causing the material to glow. In the case of zinc sulfide the radiation causes it to glow green. One recipe from 1945 lists 70 micrograms of radium sulfate to 1 g of zinc sulfide (Jones and Day 1945). There are historic accounts of the binder being gum arabic (Jones and Day 1945); another account lists the binder as linseed oil (Frame 2007). Other radioactive sources, such as thorium and tritium, have been used in the fabrication of luminescent paint; however, this article will focus solely on paints derived from radium isotopes. Paints were made with the minimum amount of binder possible, as there was concern that the binder would interfere with the radiation energy and intensity of the glow. One reason the paint is so fragile today is because the radium is breaking down the binder material and the paint may have been underbound. Radium paint that currently does not glow is due to a breakdown of the luminescent material (Warren 2010). Radium is present in some nonglowing paint; thus any suspicious paint should be checked for radiation, as there may be no visual clues that the material is radioactive. Due to the long half-life of radium, it would take 1,600 years for the radium to break down and not be present in the paint.

On two instruments with an exposed face that was not fully covered in glass, a portable Bruker Tracer III-SD XRF instrument was used to provide elemental analysis of the radium paint. A high level of zinc was found in this paint, but not in any of the surrounding black painted surface. The analysis also revealed the presence of sulfur. Although the paint analysis was very limited, preliminary elemental analysis indicates that the paint is composed of both zinc and sulfur. This is in agreement with historic recipes. Due to the health hazards and license restrictions, samples of paint could not be removed from the object for analysis. Paint covered by glass could not be analyzed due to the distance and obstruction of the glass.

3. HEALTH HAZARDS

Radium paint emits alpha and some gamma radiation. Radium decay also produces beta radiation and radon gas. Alpha particles have low penetrating power. Beta particles have a range of energy, but they are easily stopped with common shielding materials such as wood or plastic. Gamma rays travel the farthest and can penetrate many materials, including human tissue (United States Environmental Protection Agency 2015). The radium paint on the instruments in the NASM collection have a relatively low level of radioactivity. With this low radioactivity level, the primary health hazard shifts from the focus of gamma ray exposure to the danger of ingesting radioactive particles in the form of dust or paint flakes. The potential of being inhaled or ingested creates an internal hazard, which is greater than that of an external hazard of the same quantity of material. Inhaled or ingested radium increases the risk of developing bone cancer and other diseases, such as lymphoma and leukemia (United States Environmental Protection Agency 2015). Radium paint was used on instrument dials until adverse health effects were discovered. The working conditions and unfortunate health consequences of dial painters in a factory in New Jersey is well documented in books, poems, and movies about the "Radium Girls." In 1945 an article was published by the *British Journal of Industrial Medicine* that describes the protective gear worn by their radium painters in response to the conditions in the New Jersey factory (Jones and Day 1945). This was the beginning of recognizing the health hazards of radium paint. By the late 1960s radium paint was generally no longer applied to instrument dials.

The buildup of radon gas is another health hazard that needs to be considered; it is produced from the decay of radium, and exposure can lead to cancer. Large collections containing radium should be stored in a well-ventilated area to reduce radon accumulation. For storage rooms where radon accumulation is a concern, a process for monitoring the concentration of radon should be implemented.

4. MEASURING AND RECORDING RADIATION LEVELS

Monitoring and tracking exposure for people working around radioactive collections is part of a comprehensive health and safety program. For monitoring personal exposure to gamma, beta, and x-rays, using a dosimeter that is worn on the body or an extremity is appropriate. Depending on the intended use, instant readings or exposure over time can be measured, the latter of which enables data tracking. Various types of dosimeters exist, including photographic film, thermoluminescent dosimeters, pencil dosimeters, and electronic dosimeters. A subscription service typically is purchased from a certified laboratory for a relatively low cost to provide dosimeters and dose reports. Systems may be purchased to read the dosimeters on-site, which is usually practical for larger numbers of users. Pencil and electronic dosimeters are reusable direct reading instruments. These will provide a measure of dose that can be read by the user throughout a monitoring period. Exposure dose results are typically in units of millirem (mrem) per monitoring period, such as an hour, week, month, quarter, or year. The United States Nuclear Regulatory Commission (NRC) has established an annual cumulative exposure limit of 5,000 mrem for employees exposed to radioactive material.

Radiation detection instruments come in a variety of types, from nonportable stand-alone or countertop instruments to handheld detectors such as Geiger counters. All instruments have their strengths and weaknesses, so it is important to use an instrument appropriate to the purpose (type of decay and energy) and calibrated for the type of survey intended. It is common for the calibration method to be noted on the side of the instrument. If not, consult the person or company who provided the meter.

For the purpose of this discussion, we will briefly highlight several instruments most commonly used for surveys: wipe counters for detecting removable contamination and dosimeters used to document personal exposure. The simplest and perhaps most fundamental of all instruments are handheld survey meters, which comprise the meter body and the detector. Sometimes the survey meter is a separate instrument body with a detector attached by a cable. Other models may have the detector built into the body of the instrument. One of the most typical types of detectors is the Geiger-Müller, or GM detector, often termed the *Geiger counter*. The GM detector is a very good general-purpose detector capable of detecting alpha and beta particles as well as photons of x-rays or gamma rays. It can be used for the detection of radium, but for some isotopes with very low energy, the efficiency of the GM detector declines. If the energy is low enough it may not even be detected. Such is the case for low-energy beta-emitters such as tritium or low-energy gamma-emitters such as iodine-125. Properly calibrated, such instruments will detect the alpha and gamma energy of radium-226, commonly found in watches, clocks, instruments and gauges, or dials. These instruments are typically calibrated as rate meters, with the meter results provided in units of counts per minute; however, they also may be calibrated for exposure rate in units of milliroentgen per hour (mR/hr). A GM detector is highly energy dependent, so depending on the purpose of the survey, correction factors may need to be considered. NASM has access to a wide variety of survey instrumentation, and we typically use Ludlum Model 3 handheld survey meters, with either a Model 44-9 alpha-beta-gamma detector or a Model 44-7 beta-gamma detector. These are calibrated on a yearly schedule by a qualified technician (in our case, a contracted company called RSO, Inc.). Using the back of the 44-9 pancake detector allows recording of the gamma levels in the NASM Collections Information System (The Museum System database). The front of the pancake detector can also be used as a tool to identify the presence of alpha particles emitted from radium-226.

The scintillator detector is another practical detector used for general scanning to identify whether or not radioactive material is present. Scintillation detectors can be used to detect radioactive material at much lower levels than that of a handheld instrument. These detectors come in various types and can be connected to a survey meter. A liquid scintillator detector is used at NASM. To operate this detector a cotton swab or paper disk (also called a *wipe*) is touched to the surface of an object with care not to touch exposed or friable paint, as shown in figure 2.

Any radiation "leaks" or removable surface contamination are picked up by the paper or swab. The swab is then placed in a vial of scintillation cocktail, which is a solvent that contains scintillators and surfactants. The vials are run through the scintillation detector and radiation on the swab is recorded. The unit can run many samples at one time. Depending on the type, they may be suited to low-energy gamma, higher-energy gamma, or beta and gamma energy. An alpha-beta counter can also be used to record the radiation level on a cotton swab or paper disk.

Ion chambers, microR meters, and energy-compensated detectors are grouped together because they are typically calibrated for exposure rate in units of milliroentgen per hour or microroentgen per hour (μR/hr). These instruments provide a measure of ionization in air; for x-rays and gamma rays, the measured results are comparable to the dose rate. Ion chambers may be useful for gamma and x-rays when the exposure rate is greater than a few milliroentgen per hour. Energy-compensated detectors help to flatten the energy response curve and are capable of measuring gamma and x-rays approximately 10–100 times below 1 mR/hr with background radiation in the range of 0.01–0.05 mR/hr. A microR meter, as the name suggests, will typically detect energy 1,000 times less than a typical ion chamber or about 3–10 μR/hr for background. All of these detectors tend to have a relatively flat energy response as

Fig. 2. Taking a wipe from the exterior surface of an instrument face (Courtesy of Amelia Kile)

opposed to GM and scintillation detectors. Any meter appropriate for the type of decay and energy response may provide useful information if the calibration and measurement technique are known. Typically, some form of exposure rate measurement is useful for providing a measure of dose to ensure compliance with exposure limits for staff and the general public.

A simple combination of these tools, selected by purpose and need, will enable individuals to evaluate and monitor personal exposure to the staff and the public, as well as proper management of collections containing radioactive material. The documented results will provide reasonable records of exposures and contamination control, which are key elements in a radiation safety program. GM detectors may be purchased and used with relative ease. In addition, outside laboratories and consultants may be useful in conducting surveys, calibrating instruments, or analyzing wipes for contamination detection.

5. WORKING WITH THE NUCLEAR REGULATORY COMMISSION

Because the Smithsonian Institution is a federal entity with a large collection of radioactive objects, these objects are licensed by the NRC. In addition to conservation work for display, tasks were completed to meet the requirements of the NRC license. Managing radioactive collections in storage and in preparation for display will be discussed in the context of developing a practical system for working with a radioactive collection.

Simply owning licensed radioactive collections objects, particularly individual aircraft instruments, is an extensive undertaking. It requires significant advance preparation and collaboration involving multiple parties and departments, because when more than 100 radioactive instruments are located in one place and not installed in an aircraft or vehicle, state regulators or the NRC may require the owner to either reduce the number of instruments they own or apply for a specific license that governs possession of those objects beyond more general laws and regulations. For example, as the Smithsonian Institution has more than 100 such objects, the NRC has issued a specific license that applies a greater degree of regulatory compliance. The license requires more frequent and extensive inventory than the museum's regular collection-wide cyclical inventory. Inventory and disposal records must be made available for unannounced NRC inspections. Our license also requires "leak testing" radium-containing objects for removable contamination at regular intervals and before transport. Testing for removable contamination or leaks is done using a liquid scintillation counter. Radiation safety training for staff, routine surveys, survey instrument calibration, and adequate documentation are required elements of our license.

Preparing instruments for display requires additional health and safety policies and procedures to be in place. Records must be kept documenting that proper procedures are followed and tests performed to keep work areas from becoming contaminated. Up-to-date signage needs to be posted, possibly including NRC Form 3. Maintaining radioactive objects on display also requires regular inventories and leak testing. The NRC treats individual instruments much differently than those installed in aircraft. Typically for NASM, there is not public access to aircraft cockpits and leak tests are not required. Leak testing for individual gauges on display must be performed by licensed personnel. Staff with access to display cases containing radioactive objects are informed of their locations and properties so that they can take proper precautions when accessing those cases.

Obtaining training for handling radioactive artifacts can be challenging. For scenarios in which multiple people will encounter radioactive objects in a collection, having an outside resource brought in to address training for specific needs and uses is likely the best route. In addition, being knowledgeable about the level of training required by local or federal regulators is strongly advised, whether for routine handling or conservation treatment. The Smithsonian Institution is fortunate to have a safety office with resources to address health and safety concerns. Independent services and labs are available as well. We work closely with the radiation safety officer (RSO) and followed his guidance for this display. The RSO continues to work as a point of contact with the NRC to increase understanding of how possession and use of radioactive materials in museums is unique from other industries. This dialogue could influence how regulations are applied at NASM. Any changes that could come about for the application of regulations could serve as a precedent at the state level for cultural institutions and historic artifacts. NASM's institutional knowledge about managing the instrument collection has developed markedly as a result of working more closely with the NRC and health and safety experts, and our procedures have evolved and improved accordingly.

6. STORAGE AND SHIPMENT OF OBJECTS WITH RADIUM PAINT

Several issues are prominent in storing radium-painted instruments properly for long-term preservation, regulatory compliance, and health and safety concerns. These issues include radon gas emissions, protective housing to prevent dial face breakage, physical security, and contamination control.

Proper ventilation is essential for storing even a small number of radium-containing objects, as radium decay can cause an accumulation of radon gas at levels inappropriate for both residential and occupational exposure. This means that storage and display areas may need to be tested for radon and ventilation for those areas may need to be evaluated. A procedure for venting cabinets may be sufficient, or a dedicated ventilation system may be necessary. NASM has come to the conclusion in more than one situation that open shelving is preferable to ventilated cabinets for long-term storage at our facilities, because the cabinets do not significantly contribute to already multilayered security and they are cost-inefficient. Additionally, dedicated cabinet ventilation systems are more complex and may be prone to maintenance issues.

Several organizations recommend housing radium-painted instruments in bags (Ashton 1993). Although housing instruments in bags and additional handling containers may be prudent to reduce the risk of contamination, we have concluded that polyethylene bags do not have the added benefit of significantly reducing radon accumulation. Polyethylene is a cost-effective and easy-to-implement choice of material for bags to contain potential particulate contamination such as paint flakes. The diffusion coefficient for radon through polyethylene is lower than the radon diffusion coefficient through air or water (Leung et al. 2007). This means that radon will move slower through polyethylene than it will through air or air with a moisture vapor barrier. As the radon is moving at a slow rate through polyethylene, some radon will remain contained within the enclosure; therefore, the bag should be opened in a well-ventilated area or in a fume hood. Considering that the primary purpose of the bag is to contain paint particles and not trap radon gas, the thickness of the bag can be varied. Variations in the thickness of the polyethylene bag or additional layers of bag will affect the diffusion of radon. The method of bag closure is not critical to contain radon, as the radon can escape through the polyethylene. Since the NASM instrument collection is routinely accessed to meet criteria for the NRC license, objects were placed in polyethylene bags with a zipper-style seal and housed in archival corrugated board boxes to provide easier access to the collection. Bags made of other material (e.g., Marvelseal) pose several problems, such as difficulty in quickly and effectively resealing the bag as well as relatively high cost. For a situation where the object does not need to be accessed for long periods of time, material like Marvelseal may be a good option but requires future research.

Storage shelves should be periodically wipe tested if objects or containers are found to be contaminated with radium paint particles. These wipes will determine the level of radon daughter product. Radon daughters, or radon decay products (e.g., polonium-218 or lead-210), are solids and can adhere to surfaces and dust, unlike radon gas. If the wipe analysis shows elevated levels of radiation, the shelves can be decontaminated and resampled to ensure that levels are acceptable. Contamination by radon daughter products can be differentiated from radium contamination by allowing the wipe to decay, since radon daughter products decay much faster than radium.

Information about packaging, labeling, and documenting transportation of radioactive material for those with an NRC license is contained in Title 10 of the Code of Federal Regulations, Part 71. Many of the packaging requirements for objects like radium-painted dials are no greater than the standard or best practices for cultural institutions; however, they are more specific. For safe handling and hazard communication at NASM, particularly for instruments in storage, we have adopted some labeling and packaging similar to that required for transporting radioactive materials, including markings with exposure rates, dates, isotope, and standardized radioactive labels on multiple sides of the container that houses the object. A removable tag is also placed on the object. Each record in the collections database has a hazardous materials flag that appears at the top of the record, which is specific to radiation. Survey meter results and results from tests for removable contamination are recorded in the database for each instrument tested, along with the date, storage location, names of staff, instrument calibration information, and specific locations tested on the object.

Several companies provide training either with distance-learning courses or by an in-person instructor for a group for people who may need to ship objects containing radioactive materials. This training is particularly helpful for collections managers and registrars, to be aware of the requirements imposed by the U.S. Department of Transportation and the International Air Transport Association, even though a contracted company would typically be the carrier. Training is mandatory for anyone preparing a package of hazardous material or dangerous goods, which includes radioactive material, for shipment by a commercial carrier such as FedEx or UPS.

7. SETTING UP A DESIGNATED WORK SPACE AND PERSONAL SAFETY EQUIPMENT

Space at two facilities of NASM was established to conduct work on radioactive objects. A small side room in the Emil Buehler conservation lab at the Udvar-Hazy Center was set aside for this work, as it had the advantage of being in a clearly separate work space within a room with a closeable door. Being behind a closed secured door during public tours was desired to limit public access, exposure, and concern about radioactive material. The main conservation lab and side room are labeled with NRC-required signs (Form 3) informing all individuals that materials in these spaces may be radioactive. In each work space a portable high-efficiency particulate air (HEPA)-filtered fume hood designated for radioactive material was utilized. These fume hoods were labeled and inspected routinely by the Smithsonian Office of Safety, Health and Environmental Management. The work surfaces of the fume hood, tables, carts, and storage shelves were lined with a material called Benchkote. This liner and similar products are commonly used in research and production laboratories in the biology, medical, and chemical industries. One side is a textured cellulose that can trap dust particles, and the other side is a thick layer of polyethylene that prevents the transfer of liquids.

At NASM's Paul E. Garber storage facility in Suitland, Maryland, a similar workspace was equipped with a HEPA-filtered, radioactive-materials–only fume hood and a dedicated vacuum with a HEPA filter. Since work tables and carts were not used exclusively for radioactive materials, they were lined with Benchkote when work with the instruments was being performed. At the end of each work period when the table or cart was no longer being used for the instruments, the Benchkote was removed. The work surfaces were surveyed for removable contamination, and the results were recorded and posted. Contamination was not an issue for this project, but equipment, training, and supplies to properly clean up and dispose of possible contamination were available.

Protective gloves, masks for dust particles, and protective or disposable clothing (e.g., a lab coat) were also used. All tools were retained in the designated work space and were marked with a radioactive label until the project was complete and/or the tool was tested and found not to harbor surface contamination. A lead-free apron was worn when desired to protect workers from radiation. To keep exposure as low as reasonably achievable (ALARA), it may be advisable to use shielding when, for example, working for longer periods of time in a location where close proximity to gauges and/or radium-painted toggle switches is unavoidable. Aprons and/or lead shields are generally not required for this application, but a dosimetry program would provide the information to make this determination.

8. TREATMENT PROCEDURES FOR RADIOACTIVE OBJECTS

Conservation treatment steps were adapted to provide the best care for the object while working safely with a hazardous material and meeting the NRC requirements. This included working in the designated work space and using Benchkote on all work surfaces. To minimize the risk of contaminating the background paper used for photography of nonradioactive objects, a system was devised in which radioactive objects were placed on a cart covered in Benchkote. The cart was then rolled into the photography area *in front of* the background paper. This had two advantages: the cart itself was moved to photograph all sides, preventing direct handling of the object, and the object was never in direct contact with the photo paper.

Treatment focused on the exterior of objects and on instruments with exposed paint. Due to limited access and a desire for limiting radiation exposure time, treatment of the radium paint was minimal. Radium paint was consolidated and coated with 5% (w/v) Paraloid B-72 in acetone, applied by brush where possible. The stock solution of Paraloid B-72 was labeled radioactive, and at the conclusion of the project the remaining B-72 was disposed of as radioactive waste. This acrylic resin and solvent carrier did not adversely interact with the radium paint. Two applications of Paraloid B-72 were sometimes necessary in situations where a thick topcoat of acrylic was desired to help block alpha radiation particles. The consolidant helped to reduce the risk of the spread of contamination and the health hazard of friable paint. The testing of other consolidants was not carried out, as mock ups of radium paint could not be fabricated. There is a precedent at NASM of using Paraloid B-72 on radium paint (e.g., on toggle switches manufactured with a dot of exposed paint), and we have found the acrylic resin to be a stable consolidant over time and in various storage conditions. The paint binder was not analyzed due to limited physical access to the radium paint and the fact that no radium paint samples could be removed from the object. It would have been desirable to test various consolidants and analyze the paint binder; however, because of the hazardous nature of the paint, these steps were not possible. Inpainting was carried out on the instrument face only if the face was accessible, it was deemed absolutely necessary, and if the time to inpaint could be kept to a minimum to limit exposure to radiation. It should be noted that disassembly of instruments containing radium paint is not allowed except by specific authorization with the NRC or an agreement state. Agreement states have some regulatory authority over radioactive materials, as they have signed agreements with the NRC.

Other treatment steps included cleaning and stabilizing the exterior surfaces, inpainting nonradium paint where necessary, and addressing metal corrosion. The work space and tools were monitored and tested with a survey instrument and/or wipe samples at the end of each day to identify contamination and determine appropriate disposal. Materials tested include gloves, lab coats, Benchkote, and packing material as shown in figure 3.

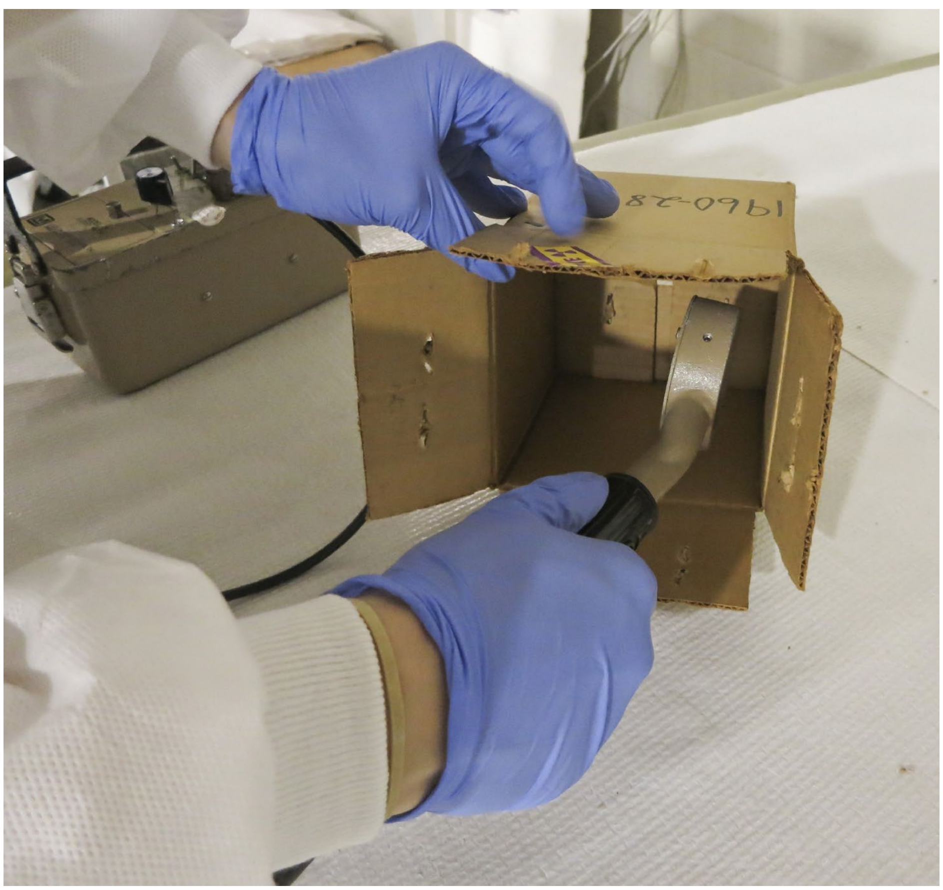

Fig. 3. Testing a box with a Geiger counter for radioactive paint flake contamination (Courtesy of Sharon Norquest)

Materials used for treatment, such as cotton swabs or Kimwipes, were disposed of as radioactive waste. At the end of a workday a wipe test was carried out on the workbench, floor, and fume hood. All results of these wipe tests were recorded in a binder that could be checked during NRC inspections.

For disposal of radioactive waste, material with a short half-life can usually be held on-site in proper storage for decay until only ambient or background levels of radioactivity remain. This is not an option for Ra-226, as its half-life is about 1,600 years. At NASM all radioactive waste is inventoried and placed in a specialized and labeled waste barrel in a secured area. It is then picked up by a licensed contractor who transports the material to Clive, Utah, for disposal.

9. DISPLAY CONCERNS

The primary concern with the display case was to determine if the public exposure was below the 2 mrem/hr requirement. The general public radiation limit established by the NRC is 100 mrem/yr (United States Nuclear Regulatory Commission 2014a). The public exposure limit at the outer surface of the case is 2 mrem/hr (United States Nuclear Regulatory Commission 2014b). With these guidelines a visitor can stand in front of a display at NASM for at least 50 hours. To test the potential level of exposure, instruments with the highest levels of radioactivity were temporarily placed in the case during the museum's closed hours. The exposure rates were recorded with a handheld survey meter at the outside surface of the clear acrylic vitrine. Even with many radioactive instruments in one large display case, the measured exposure rates for the public did not exceed the limit. The clear acrylic acts as a shield for the alpha particles. The distance between a radioactive instrument and the public was also considered, as the radiation exposure drops exponentially with an increase in distance. Two objects with higher radiation levels were placed at the back of the case farthest from the public. By moving these objects back, the levels of radioactivity just outside the case were kept as low as possible. No objects needed to be shielded or removed from the original layout.

The display case will only be opened by trained staff who are monitored through the dosimeter program. These staff will follow precautionary procedures each time the case is opened in the event of unexpected radon accumulation. The radon levels in the case will be monitored and the case ventilation will be retrofitted if it becomes necessary. The case has a security system that provides reasonable accountability and control, because all licensed radioactive material must be secured against unauthorized access. Concerns for light, temperature, and relative humidity were not out of the ordinary. A section of the case receives direct sunlight during certain times of day and year, so care was taken to display only the least sensitive objects in this section and UV film was installed.

Another challenge was to set up a display mock-up with the exhibits team to determine object placement within the case. To accomplish this task, tables were lined with Benchkote and objects were retained in their handling trays. Staff trained to work with radioactive objects handled the objects during this display mock-up while the curator and exhibit designers determined object layout in the display case. For the case, lining for the glass shelves was not necessary. If the exhibit is deinstalled, shelves would be checked for contamination and, if necessary, could be easily decontaminated. A large graphic label discussing the case contents mentions their radioactivity in a historical context.

10. CONCLUSION

By establishing and following procedures we were able to conserve and display approximately 60 radioactive objects. Fortunately, all instruments and panels the curator desired to exhibit could be situated in a large display case without excluding any objects from display. Additional shielding for the public was unnecessary as well. Certain analysis and treatment steps were curtailed by stringent health and safety requirements. However, the work was completed in a manner that provided a safe working environment for the staff and a display case that is safe for public visitors has been installed, all while also meeting the requirements of the NRC. This work could not have been completed without collaboration between the Smithsonian Office of Safety, Health and Environmental Management, the curator of the collection, collections processing, conservation, and exhibits staff. The final steps of installing the instruments into the case are being conducted. It is our hope that this article is useful to others who may be embarking on the treatment and display of radioactive artifacts.

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FURTHER READING

United States Nuclear Regulatory Commission. 2015. Information for Radiation Workers. http://www.nrc.gov/about-nrc/radiation/health-effects/info.html

SOURCES OF MATERIALS

Benchkote
  Manufactured by Whatman
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  http://www.gelifesciences.com/webapp/wcs/stores/servlet/catalog/en/GELifeSciences-au/products/AlternativeProductStructure_17131/28418846

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