

Ionizing Radiation in Conservation Labs Part 1: Monitoring Equipment

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September 2020

Introduction

Ionizing radiation can be a concern for conservation professionals, not only because it is emitted by some of the instruments used to conduct analysis but also because some collection items are radioactive. Collections and instruments emit different kinds of radiation; these radiations present different dangers, can be blocked by different materials, and different detectors are required to monitor for them. Everyone already accrues naturally occurring radiation and some from medical procedures, but it is important to aim to receive an annual dose that is as low as reasonably achievable (ALARA). This means there are choices to make when determining what monitoring equipment may be best for a lab. While some organizations are guided by institutional safety protocols, others must research on their own. This poster presents general information for reference alongside results from a survey of current practices, with information regarding available monitoring technology. The survey was distributed to the conservation community via the AIC Global Forum in 2020, and it asked about use of ionizing radiation producing equipment, radiation monitoring equipment, and radioactive collection objects (the last is addressed in a separate poster titled Ionizing Radiation in Conservation Labs Part 2: Radioactive Objects).

Types of Ionizing Radiation

The following are types of radiation you may see referenced when researching radiation monitoring equipment.

Alpha	Beta	Neutron
<ul style="list-style-type: none">Can be emitted by collectionsEasily blocked by even paper or skin, and can only travel centimeters in airDangerous if source material is inhaled/ingestedNot detected by dosimeters	<ul style="list-style-type: none">Can be emitted by collectionsPenetration varies depending on particular energy, but even high energy β-particles can be shielded by Plexiglas/Lucite/etc (do not use lead!)Instrumental source: beta plate radiography	<ul style="list-style-type: none">Almost never found in the museum environmentVery dangerous, but very rare unless in certain conditions (e.g. working with a nuclear reactor or certain synthesized radioisotopes)
X-ray	Gamma	
<ul style="list-style-type: none">Commonly produced by certain analytical instruments in a laboratory settingSources include: X-radiography, XRF, XRD, PIXE	<ul style="list-style-type: none">Can be emitted by collectionsHighest energy on electromagnetic spectrum, usually produced at the same time as alpha and beta decayHigh penetrationInstrumental sources include: PIGE	

What is Measured?

There are many quantifications of radiation (activity, exposure, dose, equivalent dose, etc.), each with multiple unit options. Some are measured directly with the equipment discussed in this poster, while others can only be estimated through calculations. Calculations involve factors such as the biological effects of different radiations and the sensitivities of different organs and tissues. There are many types of radiation detectors. This is why you need a dosimeter or other dose monitoring device to know dose; you can't just multiply readings from other instruments by time. It can get confusing! Seek professional help if you have any questions.

In this poster you will find the unit "rem" and the SI unit sieverts (Sv) used to express radiation doses.

$$1 \text{ Sv} = 100 \text{ rem}$$

The US federal limit for the annual total effective dose equivalent for the whole body is **5,000 mrem** (5 rem) for trained employees exposed to radioactive material. The limit for the public and untrained employees is **100 mrem**.

You may also see doses reported as Hp(10) or Hp(.07). This is the personal dose equivalent with the variable of depth to indicate whether what is being monitored is a shallow (.07mm) or deep (10mm) dose.

Geiger counters/survey meters

61.8% of survey respondents use a Geiger counter in their work.

In most survey meters, the charge created when radiation creates ions in a gas-filled chamber is amplified. Not all survey meters employ a Geiger Müller tube, but similar instruments are sometimes still referred to colloquially as "Geiger counters."

Geiger counters...

- Detect the presence of radiation, but cannot differentiate between types of radiation
- Need to be calibrated if they are to be of any quantitative value, or at least checked to be sure of sensitivity for qualitative work.
- Are not all equal, different models detect different radiations and have different sensitivities. Contact the manufacturer for detector response specifications.

Geiger counters can be used to...

- Check for radioactivity of a collection item
- Check for effectiveness of shielding equipment
- Check for leakage from instrumentation

Most Geiger counters commonly used in conservation labs do not indicate personal exposure, do not differentiate between types and energies of radiation, and cannot be used to calculate dose.

Dosimeters

66.7% of survey respondents (or their institutions) use ionizing radiation emitting equipment. **85.7%** of those respondents use a dosimeter in their work. A small percentage of respondents do not use ionizing radiation-emitting equipment but do use dosimeters in their work with radioactive objects.

There are many different types and detectors available, which mean they each have varying sensitivities, costs, and flexibility of use. Some are considered passive and need to be read by a second machine, sometimes at a parent company, in order for the wearer to obtain a result. Others are active and can give the wearer a real-time reading of exposure.

Types of detectors include:

Film- Film badges are an older technology using a combination of photographic film and filters. These have mostly been replaced by the alternatives.

Thermoluminescence (TLD)- These are commonly worn on the chest. The detector is a series of crystals. When heated, the amount of light indicates the amount of radiation absorbed by the crystals. They need to be sent in to a company to be read.

Extremity/rings- These are often TLDs, worn on the fingers/hands, often if working with radioactive objects or instrumentation. The risk of damage from radiation exposure to the hands is significantly less than risk to the organs, but hands are often put closest to the source of radiation.

Optically Stimulated Luminescence (OSL)- These function similarly to TLD badges, except the detecting crystals are activated through light rather than heat.

Ionization Chamber/Direct Ion Storage (DIS)- As radiation ionizes gas in a sealed chamber with an anode and cathode, the ions move to the electrodes, and the charge that is produced is measured. In DIS dosimeters, this is combined with a memory cell, which stores the charge so it can be read.

Silicon Semi-conductor- Charges (freed electrons and the gaps they leave behind) are created in the semiconductor material as radiation travels through the crystal lattice. That energy is collected by an electrode and read.

Some survey respondents use multiple types of dosimeters and Geiger counters in their work, for different applications. For example, as many of the dosimeter options currently available do not offer the wearer a real-time observation of radiation exposure, they can be used in conjunction with Geiger counters, etc. Another example is when analytical scientists wear ring dosimeters in addition to badges during handheld XRF work. Some people have badges issued for their staff, but choose a different device that does not need to be sent out for reading to assign for temporary work, such as when a contractor comes in. Keep your own working needs in mind when deciding what you may want. If you work somewhere that is overseen by a safety organization, get in touch if you have not already. They will be able to advise on what is best for your work.

Reference Table for Available Dosimeters

Refer to the table below for a selection of commonly used and readily available dosimeters. The inclusion or exclusion of dosimeters in this selection is not a judgement or endorsement by the authors. They are dosimeters being used by survey respondents or similar ones found in research, and the listed vendors are where they seem to be most readily available. Costs are approximate, and may vary depending on the number of dosimeters purchased in a batch, frequency of return for readings if necessary, and availability. Depending on your location you may have different available dosimeters, or even the same/similar dosimeters available through different vendors.

Type	Brand and Manufacturer	Readout Info/Timing Detector Type Other features (alarm, storage, etc?)	Types of Radiation Detected	Response Information	Cost (est.) per dosimeter
Thermoluminescent Dosimeter (TLD)	Genesis Ultra TLD (Mirion Technologies)	Return to company for report (1 week to 6 months) Detector: 4-Element TLD: 3 7LiF:Mg, Cu, P (TLD700H) and 1 6LiF:Mg, Cu, P (TLD600H)	Beta Gamma X-ray Neutron	Energy Response: Beta: 0.251 MeV - 5 MeV Photon: 5 keV - 6 MeV Neutron (TLD): Thermal - 6 MeV Neutron (CR39): 200 keV - 6 MeV	\$170/year (if returning quarterly)
	TLD-XBGN (Radiation Detection Company (RDC))	Return to company for report (Monthly, Bi-Monthly, or Quarterly) Detector: 4-Element TLD	Beta Gamma X-ray and will show presence of Neutrons	Energies Measured: Beta 76 keV - 5 MeV Photon 20 keV - 6 MeV Minimal Reportable Dose: 10 mrem (.10 mSv)	\$69/year
	Radiation Detection Company (RDC) - TLD-XBGN Neutron Dosimeter	Return to company for report (Monthly, Bi-Monthly, or Quarterly) Detector: 4-Element TLD w/ Track Etch added for low energy neutrons	Beta Gamma X-ray Neutron	Minimal Reportable Dose: 10 mrem (.10 mSv) for Dosimeter and 20 mrem (.20 mSv) for Track Etch	Estimate Not Obtained
Rings/Extremity (also TLD)	XTLD-XBG Extremity (Radiation Detection Company (RDC))	Return to company for report (Monthly, Bi-Monthly, Quarterly) Detector: Single Element Dosimeter	Beta Gamma X-ray	Energies Measured: Beta 76 keV - 5 MeV Photon 20 keV - 6 MeV	Estimate Not Obtained
	MeasuRing (Mirion Technologies)	Return to company for report (1 week to 6 months) Detector: Single Chip nLiF:Mg, Cu, P Powder Chipstrate (TLD100H)	Beta Gamma X-ray	Energy Response: Photon 20 keV - 6 MeV Beta 0.251 MeV - 5 MeV Useful Dose Range: 0 mrem - 1000 rem (0.20 mSv - 10 Sv)	\$170/year (if returning quarterly)
	Saturn Rings (Landauer)	Return to company for report (variable, often quarterly) Detector: Natural lithium fluoride TLD	Beta Gamma X-ray	Energy Range: Photon (x or gamma ray) - greater than 15 keV Beta particle expressed as average energy - greater than 200 keV Dose Measurement Range: Photon (x or gamma ray) - 10 mrem to 1,000 rem (100 μ Sv to 10 Sv) Beta particle - 10 mrem to 1,000 rem (100 μ Sv to 10 Sv) Detection outside these ranges can be requested	\$170/year
Optically Stimulated Luminescence (OSL)	Luxe+ Chest Dosimeter (Landauer)	Return to company for report (variable, often quarterly) Detector: Al ₂ O ₃ :C (Aluminum Oxide) Optional Neutrak® 144 detector inside dosimeter CR-39 to detect neutrons	Beta Gamma X-ray (Neutrons optional)	Energies Detected: Beta particle: 150keV to in excess of 10MeV Photon (x and gamma ray): 5keV to in excess of 40MeV Dose Measurement Range: Beta particle: 10 mrem to 1000 rem Photon (X-ray and Gamma): 1 mrem to 1000 rem Optional additional detector for neutrons	\$140/year
	InLight Nova OSL Dosimeter (Health Canada program)	Return to company for report Detector: 4-element OSL: crystalline aluminum oxide doped with carbon (Al ₂ O ₃ :C) with filters of thin mylar plastic, thick plastic, aluminum, and copper	Beta Gamma X-ray	Energy Response: Photon (X-ray and Gamma): 20 keV to in excess of 6000 keV Beta (Max): 687 keV to in excess of 2274 keV Doses Reported: Hp(10) and Hp(0.07) Reporting Threshold: 0.10 mSv	Estimate Not Obtained
Ionization chamber-based	Model W138 (Arrow-Tech Inc.)	Direct-reading, can read accumulated dose at any time (requires noting current dose when you put the dosimeter on) Detector: carbon-fiber electroscop with an ion chamber	Gamma X-ray	Radiation Detected: from 16 keV to 6 MeV Range: 0-200mR Accuracy: +/- 10% of true exposure Rate Response: Dose rate independent for Gamma and X-Ray	\$150 per unit (plus cost for ~yearly calibration)
	Instadose USB dosimeters (Mirion Technologies)	Instant readout at any time through USB Direct Ion Storage device	Gamma X-ray	Energy Response Photon 5 keV - 6 MeV Minimum Reportable Dose 3 mrem (0.03 mSv) 1 mrem (0.01 mSv) upon request Useful Dose Range 1 mrem - 500 rem* (0.01 mSv - 5 Sv)	\$100 per unit \$25 annual fee
	Instadose+ (Mirion Technologies)	Instant readout at any time using Bluetooth or USB Direct Ion Storage device with BLE Technology Can set automatic scheduled readings Can set email notifications for exceeding dose limits	Gamma X-ray	Energy Response Photon 5 keV - 6 MeV Min. Reportable Dose & Useful Dose Range 5 mrem - 500 rem* (0.05 mSv - 5 Sv)	\$105 per unit \$25 annual fee
	Instadose(R)2 (Mirion Technologies)	Instant readout at any time using Bluetooth or USB Direct Ion Storage (DIS) Technology Bluetooth® Wireless Technology can set automatic scheduled readings Can set email notifications for exceeding dose limits	Beta Gamma X-ray	Energy Response Photon 5 keV - 6 MeV Beta \geq 0.8 MeV Min. Reportable Dose & Useful Dose Range 10 mrem - 500 rem Doses Reported: Hp(10) and Hp(0.07)	\$145 per unit \$25 annual fee
Silicon semiconductor/diode	DMC 3000 personal electronic radiation dosimeters (Mirion Technologies)	Instant readout on LCD display Detector: Si semiconductor adjustable dose and dose rate alarms programmable alarms with visual LED, audible, and vibrating alarm indicators	Gamma X-ray (Beta and Neutron are add-on modules)	Effective Range of Dose: 0.001 mrem to 10000 rem Doses Reported: Hp(10) and Hp(0.07)	Estimate Not Obtained
	Rados RAD60 dosimeters	Instant readout on display Detector: Energy compensated Si-Diode selectable alarm levels for both dose and dose rate	Gamma X-ray	Measurement Range Dose: μ Sv - 9.99 Sv or 0.1 mrem - 999 rem Dose Rate: 5 μ Sv/h - 3 Sv/h or 0.5 mrem/h - 300 rem/h Energy Response Hp(10), 60 keV - 3 MeV, better than + or - 25%, up to 6 MeV, better than + or - 35%	~\$600 per unit
	dosimeter Model 23 (Ludlum Measurements)	Instant readout on display Detector: Silicon semiconductor (Data is lost once turned off. Must download first.) Screen with with indicators for dose, dose rate, operating time, and audible alarm	Gamma X-ray	Dose Rate and Accumulated Dose Alarms Range: 0.1 mrem/hr to 99.99 rem/hr 0.1 mrem to 99.99 rem Gamma and X-ray (35 keV to 3 MeV)	\$407 per unit

Conclusion and Future Work

It is worth remembering that you are accumulating naturally occurring ionizing radiation every day, and even non-ionizing radiation can cause biological damage (e.g. UV light causing skin cancer). However, awareness, monitoring, and preventive measures can help reduce excess exposure to radiation and limit any negative health effects. Check your local laws and recommendations for your occupational regulations, but always aim for minimal exposure.

A second poster (Ionizing Radiation in Conservation Labs Part 2: Radioactive Objects) discusses radioactive collection objects, including more information from the survey responses, and risks and precautions to consider when working with radioactive collection materials.

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