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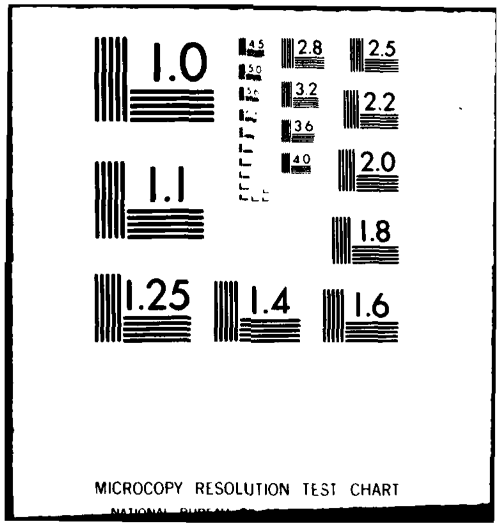
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NSWC MP 79-491

INTRODUCTION TO THERMOLUMINESCENT DOSIMETRY

BY LOUISE A. MILES

ELECTRONICS SYSTEMS DEPARTMENT

7 MAY 1980

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This publication is intended to provide a better understanding of passive radiation measurements for people performing radiation effects experiments at the NSWC Electronic Hardening Branch facilities. It addresses some of the commonly asked questions regarding thermoluminescent dosimetry of gamma and pulsed x radiation and briefly overviews the readout procedure for using thermoluminescent dosimeters (TLDs). A glossary of the basic terms used in radiation effects experimentation is also provided.

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FOREWORD

This publication is intended to provide a better understanding of passive radiation measurements for people performing radiation effects experiments at the NSWC Electronic Hardening Branch facilities. It addresses some of the commonly asked questions regarding thermoluminescent dosimetry of gamma and pulsed x radiation and briefly overviews the readout procedure for using thermoluminescent dosimeters (TLDs). A glossary of the basic terms used in radiation effects experimentation is also provided.

KURT R. ENKENHUS
By direction

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ILLUSTRATIONS

I. INTRODUCTION

Accurate measurement of ionizing radiation is one of the more formidable tasks associated with nuclear weapons effects experiments. A wide variety of both passive and active measuring techniques are used to detect and quantify ionizing radiation. This paper describes one of the most widely used passive techniques, the thermoluminescent dosimeter (TLD), and how an experimenter uses the TLD to measure ionizing radiation.

II. IONIZING RADIATION

A. General

Ionizing radiation may be produced by the decay of radioactive materials or by particle accelerators. The sources of radiation in use in the Nuclear Effects Division at the Naval Surface Weapons Center, White Oak Laboratory, include a 2000 curie Cobalt-60 source, three Flash x-rays machines (Febetrons, two Model 705s and one 706) and the Casino machine. All of these sources produce gamma rays or X-rays.

Ionizing radiation ionizes matter either directly or indirectly through secondary radiation. Ionization occurs when enough radiated energy is transferred to a material to eject electrons from its atoms or molecules. There are various types of ionizing radiation. Ionizing radiation includes photons (such x-rays, gamma rays and bremsstrahlung) and particles (such as electrons, neutrons, protons, and alpha particles). In this paper we are primarily concerned with the measurement of x-rays and gamma rays.

The machine-produced x-rays, such as those generated by Casino, are produced by the bremsstrahlung process and by atomic deexcitation processes. A continuous spectrum of x-radiation (bremsstrahlung) is produced when an electron beam is stopped or decelerated in some material called the x-ray converter material. Usually high atomic number materials like tantalum and tungsten are used as converters because they produce x-rays more efficiently than do low atomic number materials like carbon. Some of the x-rays produced interact with the materials of the test specimen giving up energy to the test specimen and producing secondary electrons. Both the x-rays and the secondary electrons can deposit energy or dose in the material of the specimen.

B. Dose

The absorbed dose delivered to a specimen by ionizing radiation is the amount of energy absorbed in the material of the specimen per unit mass of the irradiated material. The rad is a common unit of absorbed dose and is by definition 100 ergs per gram. The new SI unit (metric system unit) of absorbed dose is the gray, which equals one joule of energy deposited in one kilogram of material, therefore, 1 gray equals 100 rads.

III. TLDs

A. General

Thermoluminescent dosimeters (TLDs) are used to measure absorbed dose. The TLD crystals used at Casino are CaF_2:Mn (calcium fluoride: manganese activated. The presence of the manganese impurity in the CaF_2:Mn TL[1] increases the number of traps in the TLD. A photograph of two types of TLDs are shown in Figure 1. When TLDs are exposed to ionizing radiation, some of the electrons in the TLD crystals are excited and knocked free of their atoms. This leaves some ions with missing electrons and some free electrons. Some of the freed electrons are captured by traps which are created by the impurities and imperfections in the crystals and enhanced by the addition of the manganese. Later, when heat is applied to the crystals, these traps release their electrons which are recaptured by available positive ions. In the process light is given off. The total amount of light released from the traps when the crystal is heated is nearly proportional to the radiation dose received by the TLDs.

B. Shielding

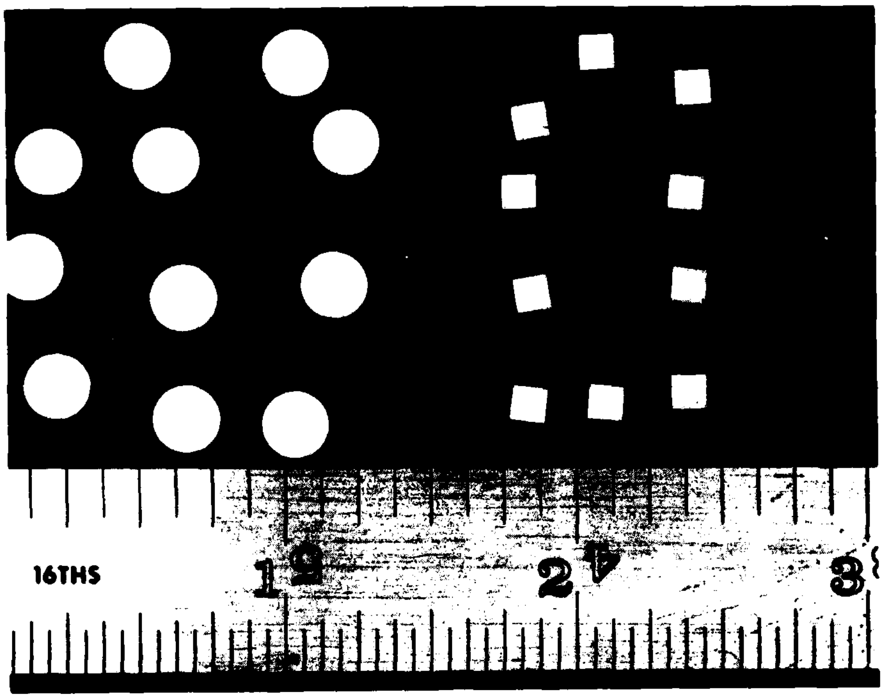
During irradiation, metal shielding of typically 1 to 30 mils of aluminum (.00254 to .0762 cm) is placed around the TLDs. Figure 2 shows some TLDs along side of their shields. The shield keeps the TLDs clean and prevents long-term exposure to room light. It also shields the TLDs from external scattered low-energy electrons which can lead to spurious dose results. A sufficient thickness of aluminum can also provide charged-particle equilibrium shielding.

C. TLD Readout

TLDs are read out using a TLD reader shown in Figure 3. The readers used at Casino are the Models 2000A and 2000B Harshaw Analyzers, which work in the following way. The analyzer heats up the TLD, giving the trapped electrons enough energy to be released from the traps. The electrons lose energy in the form of released visible light as they recombine with the ions. The glow or light output from the TLD is measured by a photomultiplier. The total integrated photomultiplier output from the TLD is displayed digitally on the analyzer in units of charge: nanocoulombs (nC) or microcoulombs (μC). This charge value is very nearly proportional to the radiation dose received by the TLD.

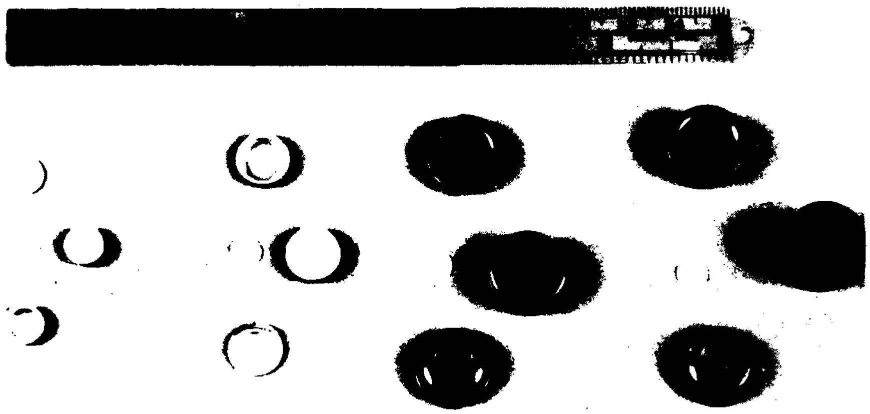
D. Fading

At room temperature there exists a thermoluminescent fading effect in the CaF_2:Mn TLDs. This effect depends on how soon after irradiation the TLDs are read out.[2] After irradiation some of the trapped electrons in the TLD material begin to escape their traps and recombine with ions. Consequently, this loss of trapped



(a) (b)

FIGURE 1 TWO FORMS OF THE CaF_2:Mn PHOSPHOR TLD. (a) THE 5% PHOSPHOR TEFLON DISC TLD AND (b) THE 100% PHOSPHOR BLOCK TLD



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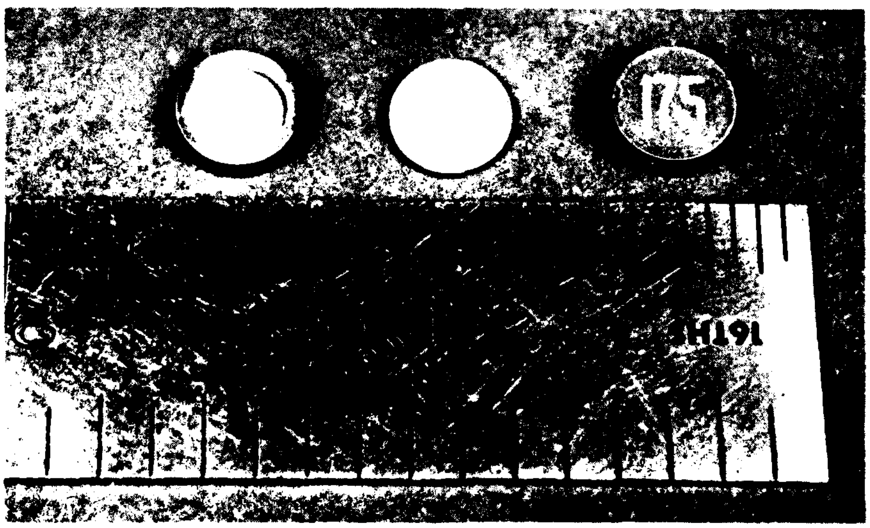
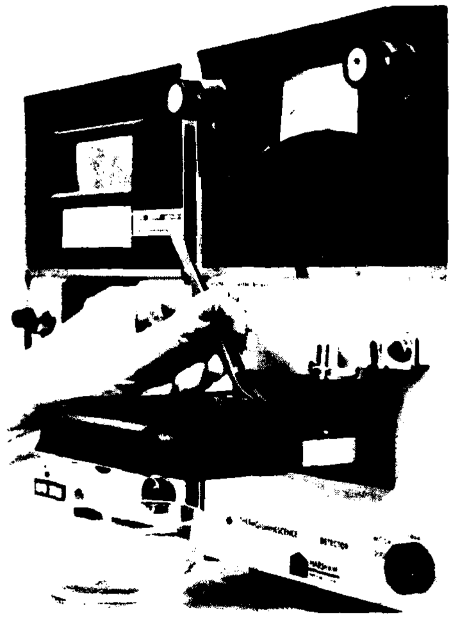


(b)

FIGURE 2 (a) FOUR TYPES OF ALUMINUM CAPSULES TO HOLD TLDS (WITH DISC TLDS). THE FIRST TWO FROM THE LEFT ARE CASINO-MADE CAPSULES. THE OTHER TWO CAPSULES ARE FROM OTHER AGENCIES AND ARE NOT USED AT CASINO. (b) CLOSE-UP OF A CASINO CAPSULE WITH A DISC TLD INSIDE OF IT.



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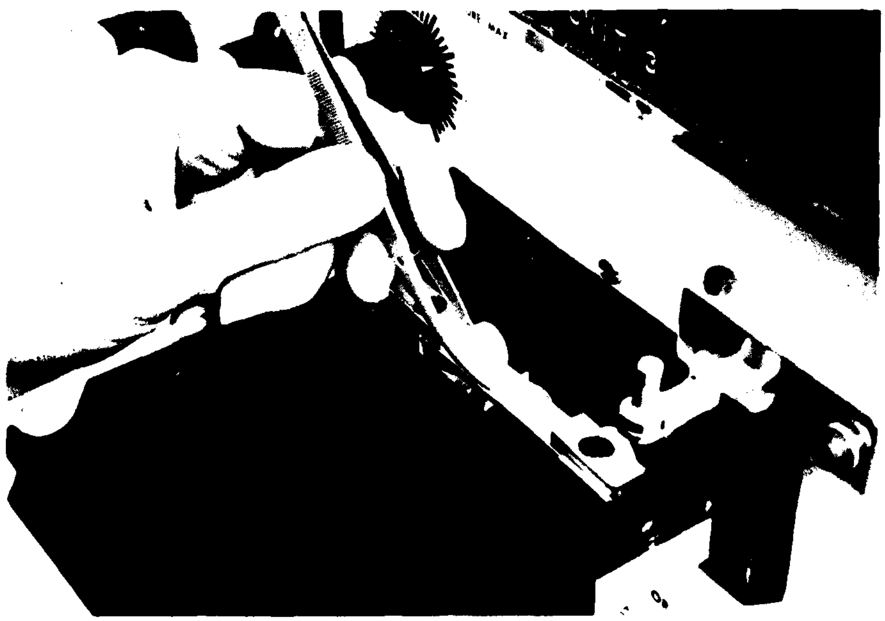


(b)

FIGURE 3 (a) A DOSIMETRY TECHNICAN PLACING A TLD ON THE PLANCHET OF THE HARSHAW 2000 ANALYZER. (b) CLOSE-UP.

electrons with time must be accounted for by the use of a fading correction factor. This factor correction factor usually small amounting to less than 15% of the dose value read and is applied automatically on every reading by the computer program that converts the analyzer reading in nC to dose (CaF_2) in rads.

E. Analyzer Setup

The Harshaw Analyser must be carefully checked before beginning readouts. Undosed TLDs and standard TLDs (TLDs irradiated at a calibrated source to a known exposure level) are read before reading out the actual test TLDs. The standard TLD readings are used to adjust the computer's programmed calibration curve for day-to-day analyzer fluctuations. The undosed TLD readings are used to subtract the contribution of background dose and analyzer effects from the irradiated TLD values.

F. Computer Processing

The digital output of the analyzer is recorded on both teletype and paper tape, as are the pertinent comments added by the operator performing the readout. The paper tape data is processed, using a Fortran program, by the Casino PDP 11/40 computer. The program applies background and adjustment corrections and converts the charge data in nC to dose values in rads using an established calibration curve. The computer line printer output is usually transposed to a more convenient format (TLD array map) for the experimenter/user. Copies are then made and distributed to the user, shot record keeper, test coordinator, and others as specified in the experimental plan.

G. Storage and Handling

When not in use, TLDs are stored in lead brick containers (pigs). This cuts down on natural background radiation reaching the TLDs and on any dose the TLDs might receive from the nearby sources. TLDs are handled with tweezers to keep them clean. Tape, pencil marks, fingers, etc., are never put directly on the TLDs as these are comtaminants. After irradiation no additional special handling procedures are required because the sources in the Nuclear Effects Division do not produce radiation of sufficient energy to make objects exposed to them radioactive.

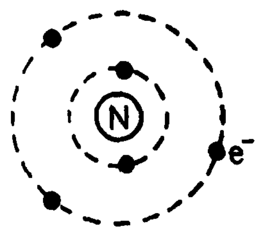
GLOSSARY OF TERMS

1. ALPHA PARTICLE

An alpha particle is a particle consisting of two protons and two neutrons (a helium nucleus) emitted from the nucleus of a radioactive atom.

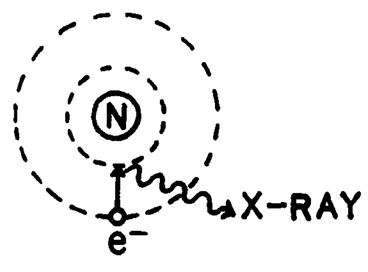
2. ATOM

An atom is the smallest component of an element that still has all the properties of the element. The atom consists of a nucleus surrounded by orbiting electrons.



3. ATOMIC DEEXCITATION

Deexcitation occurs when an atom's bound electron goes from a high energy level (orbit) to a lower energy level, giving off the excess energy in the form of characteristic x-rays.



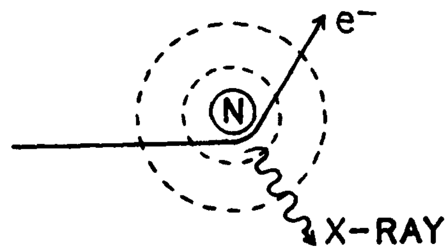
GLOSSARY OF TERMS (CONT'D)

4. ATOMIC NUMBER

The atomic number is the number of protons in the nucleus of an atom. The atomic number determines the element.

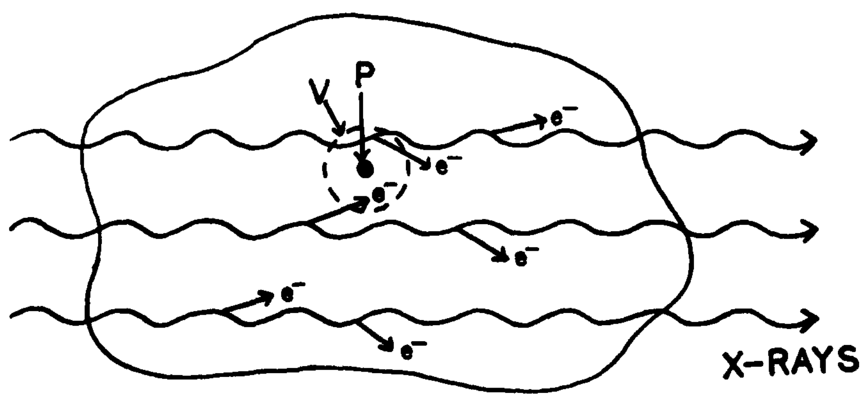
5. BREMSSTRAHLUNG

Bremsstrahlung, or continuous x-rays, are the result of the deceleration of free electrons or other charged particles. This occurs when the incident charged particles are deflected by the field of the nucleus.



6. CHARGED-PARTICLE EQUILIBRIUM (CPE)

For a given location (point P) inside some material and a small volume V surrounding P, CPE exists at P if for each charged particle that carries a certain energy out of V there is another identical charged particle carrying the same amount of energy into V. For CPE to exist, the volume V must be surrounded by a sufficient amount of material. Shielding can be used as this surrounding material to create CPE in the TLD. When CPE exists in the TLD, the equation for converting from dose in the TLD material to dose in some other material is greatly simplified. This is important for users who want to know what dose their components received. They may want dose in gold or dose in silicon instead of dose in CaF_2 (TLD material).



GLOSSARY OF TERMS (CONT'D)

7. ELECTRON (e^-)

An electron is a negatively charged elementary particle that is a fundamental part of atoms.

8. ERG

The erg is a unit of energy. It is equal to 10^{-7} joule (.0000001 joule).

9. GAMMA RAY

A gamma ray is a high energy photon emitted from the nucleus of a radioactive atom.

10. ION

An ion is an atom that is either positively or negatively charged due to the loss or addition of an electron.

11. J/kg

J/kg stands for joule/kilogram, where joule is a unit of energy, gram is a unit of mass and kilo is a prefix meaning thousand.

12. NEUTRON

The neutron is a neutrally charged elementary particle that is a fundamental part of the nucleus of atoms.

13. NUCLEUS

The nucleus is the positively charged center of an atom consisting of protons and neutrons.

14. PHOTON

A photon is a quantum (the smallest discrete bundle) of electromagnetic radiation.

15. PROTON

A proton is a positively charged elementary particle that is a fundamental part of the nucleus of atoms.

16. RADIATION

Radiation is energy that is emitted from matter as photons (x-rays, gamma rays, visible light, etc.) or particles (electrons, alpha particles, etc.). For example, light from the sun is radiation as is the energy given off by radioactive nuclei.

GLOSSARY OF TERMS (CONT'D)

17. RADIOACTIVITY

Radioactivity is the process through which the nucleus of an atom spontaneously emits radiation. The nucleus is changed during this process.

18. SECONDARY RADIATION

Secondary radiation is radiation that is emitted due to the interaction between radiations and matter. Continuous x-rays (bremsstrahlung) are an example of secondary radiation since radiation in the form of charged particles is needed to produce them.

19. SI UNITS

SI units stand for the International System of Units (the MKSA system of metric units: meter, kilogram, second, ampere).

20. X-RAY

An x-ray, in the context commonly used in weapon effects, is any photon having an energy in the range from .01 keV to nominally 200-250 keV. X-rays are classically associated with machines in the way gamma rays are associated with radioactive decay. Machines can, however, produce X-rays which are undistinguishable from gamma rays.

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