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SOME OBSERVATIONS ON
FILM BADGE CALIBRATION TECHNIQUES

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TID-4500SOME OBSERVATIONS ON FILM BADGE CALIBRATION TECHNIQUES

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BADGE CALIBRATION TECHNIQUES

Authors: A. F. Becher, N. B. Schultz,
and L. H. Sipe

A B S T R A C T

A mobile gamma radiation calibration unit utilizing a multi-curie cobalt-60 source for the interpretation of radiation dose as determined from dosimeter film measurements is described. The radiocobalt source is encapsulated in an airfoil capsule which is raised and lowered by an enclosed, recycled air stream, permitting rapid and precise positioning of the source. A wide range of dose rates can be obtained by varying either or both the distance from the source and the exposure time. Doses ranging from 50 mRad to 2,000 Rad can be obtained with only two exposure cycles. The results of tests to validate the accuracy of the film calibrations by use of a calibrated standard are presented.

SOME OBSERVATIONS ON FILM BADGE CALIBRATION TECHNIQUES

INTRODUCTION

Radiation dosimetry, in its broadest sense, is the health physics function dealing with systems and devices designed to permit the assessment of radiation dosage to personnel who may be exposed to varying levels and types of penetrating radiation, including beta, gamma, X-ray and neutron. The response of certain photographic film emulsions to these radiations is well established, and as a consequence, photographic film contained in meter badges has been widely employed as dosimeters for evaluating both acute and chronic exposure of personnel to X-ray, beta, gamma, and neutron radiations. (See Fig. 1 - ORGDP Employee Meter Badge). These film meters are relatively inexpensive, and when used in conjunction with the film packets, have been almost universally accepted within the nuclear industry as a reliable permanent record of exposure. Most manufacturers of such film provide an emulsion which is very sensitive to radiation, and when developed by standard techniques, the film will be found to be darkened in proportion to the amount of radiation received (See Fig. 2 - Processed Film); however, the photographic film alone cannot give a measurement of the quality or the quantity of radiation. In order to make such an evaluation, a series of filters having varying known densities must be used. Additionally, the film must be calibrated against known amounts of the radiations of interest so that the observed densities can be interpreted in terms of dose. Calibration involves exposing the selected dosimeter film to known quantities of radiation of the proper quality and then developing this film along with randomly selected blank film and the film used in field monitoring. After subtracting the blank density, the densities obtained from the monitoring films may be interpreted in Rads when compared with the measured densities of the calibrated film. We have found that a certified instrument response to the gamma rays associated with the decay of ^{60}Co can be obtained from the National Bureau of Standards, thus providing a standardized R-meter. This standard can then be used to measure the dose accumulated at preselected distances from commercially available ^{60}Co sources. Thus, once the initial calibration has been assessed, if one can then faithfully reproduce the time interval and source locations, and corrections for air density are made, a reliable estimate of dose can be made. Such a device and calibration procedure has been developed at the Oak Ridge Gaseous Diffusion Plant and has been in service about seven years.

DISCUSSION

Much consideration has been given to those factors which affect accurate dose determinations and which also limit the use period of film dosimeters. It has been recognized that, in addition to density resulting from an industrial radiation exposure, other factors such as normal background, radiation film aging effects, manufacturing processes, temperature,

humidity, conditions of processing, and time elapsed between exposure and processing are among those which can contribute to film darkening and, conversely, fading of the latent image can result in underestimation of the dose. However, aside from these variables, there must be provided a suitable, reproducible calibration technique utilizing a source of radiation which can be certified as to accuracy of the measured dose, not only to routinely assess the personnel exposure but also to provide a defensible record in the event of litigation. It is with some of the problems associated with the calibration of film dosimeters, in terms of Rad dose for gamma exposure, that this report is concerned.

The principal limitation in the calibration of any radiation field is the accuracy of the original sample or standard which was absolutely counted. In making preparations to secure a film calibration source larger than the 50-millicurie radium source which had been used for many years at the Oak Ridge Gaseous Diffusion Plant, the use of a radium source on the order of one curie was initially investigated. However, this was not considered to be advisable in that the National Bureau of Standards does not calibrate radium sources larger than 200 millicuries. Effects such as absorption of radiation by the source material itself, which are relatively insignificant for small sources, become quite appreciable for a one-gram source. Although corrections can be computed, the accuracy of such computations is questionable and becomes somewhat of an experiment for each calibration to be made. Also, due to the wide range of radiation energies (0.184 Mev to 2.198 Mev) of the radium gamma, there is no instrument available which will accurately measure the dose rate from a radium source, since an instrument which will respond accurately to the low-energy gamma rays may be considerably in error for the higher energies, and vice versa.

Cobalt-60, another commonly used gamma source, was the preferred choice in our case since its gamma rays have two nearly equal energies (1.33 Mev and 1.17 Mev). While the National Bureau of Standards does not calibrate ^{60}Co sources, the Bureau does calibrate high-energy Victoreen R-meter ionization chambers for response to such gamma radiations. Accordingly, a 7.2 curie ^{60}Co source was procured and an automatic source storage and utilization device was designed and built, taking advantage of both time and distance to obtain a wide range of reproducible "standard" radiation doses. The calibration source storage and exposing device permits rapid and precise positioning of the source by a totally enclosed air stream.

CALIBRATION DEVICE

Calibration is performed with the film badges positioned in permanently mounted holders at various fixed distances on a rectangular table made of 3/4 inch masonite, 2-1/2 feet wide by 8 feet in length. (See Figures 3 and 4 - Pneumatron). The cobalt-60 source pellet is enclosed in a stainless steel cylinder, which in turn is encapsulated in an aluminum dumbbell, 1/2 inch diameter by 1-3/4 inches long, which has airfoil characteristics. When not in use, the source is stored in a lead safe,

18 inches in diameter and weighing about 1400 pounds, beneath the table. The unit is mobile, being mounted on 18-inch diameter rubber-tired wheels, two of which swivel. A tow-bar permits either hand positioning or transporting with a vehicle.

Two concentric lucite tubes extend from the lead safe up through the center of the masonite table. The source rises up the inner lucite tube in an air stream provided by a blower which operates on 110-volt AC electrical power supply, and the capsule rides atop a column of air which is exhausted through a series of orifices at the desired height. A bumper-block is also provided at the top of the inner tube. The return air flows through the orifices in the inner tube and is discharged to the outer tube where it is returned to the pump suction, thus completing the totally enclosed cycle and minimizing the spread of contamination in the event of a source leak. The source is lowered into the lead safe simply by stopping the air flow either remotely by manual push-button control or automatically by means of the electric timer which has settings varying through a range of 1/4 second to 60 hours.

CALIBRATION PROCEDURES

Source positioning, as revealed by high-speed movies, is accomplished in less than 1/2 of a second. The exposure rate in mRad per hour for each badge position was measured by a high-energy Victoreen R-meter and ^{60}Co chamber located at the various badge positions. Both chamber and R-meter were previously calibrated and certified by the National Bureau of Standards. The useful range of the device is indicated by the 28 film badge positions which provide exposures from 50 mRad to 10 Rad and 10 Rad to 2000 Rad at exposure times of one minute and 200 minutes, respectively, as shown in Figures 5 and 6. This device is used for routine meter badge calibrations, as well as such other investigations and studies as the latent image fading on film exposed to radiation, the effects of back-scatter from phantoms, and the evaluation of silver metaphosphate glass rods and thermoluminescent powder as personnel gamma dosimeters.

Initial badge positioning based on calculated distances to obtain given dose rates resulted in errors of as much as about 10% in the Rad dose actually delivered at the surface of the dosimeter. This is attributable to the fact that the inverse square law does not hold precisely due to such factors as buildup, scatter radiation, and secondary electron emission from materials in the surroundings which have been exposed to the primary field.

It is desirable to have a known gamma spectrum since the film emulsion is energy dependent in the low energy ranges. Since ^{60}Co emits two nearly equal gamma ray energies of 1.17 and 1.33 Mev, it is frequently assumed that these are the only energies being measured. This is not correct since there is degradation of energy due to Compton effect (about 250 Kev) in the source material itself, and scattering (about 500 Kev) from background materials such as the air, walls, floor,

ceiling, etc. It is also desirable that the gamma spectrum be in equilibrium with air equivalent materials. In this case, we mean that condition where as many electrons are stopped in a slice of the material as are originated there. Backscatter effects can of course be minimized by locating solid materials an appreciable distance from the source and the badges being calibrated. Equilibrium, on the other hand, can be achieved by providing additional filtration at each badge position. For our case, this consisted of 1/32 inch of lead and 1/4 inch of plastic (plexiglass) filters to absorb the electrons emitted from materials between the radiation source and the dosimeter. While these filters reduce the dose rate slightly, the time can be adjusted as necessary to obtain the desired dose.

The adjustments made permitted each badge position to be normalized, thus providing a reproducible film density for a given dose at all badge locations. Checks of doses at the 28 badge positions reveal a statistical limit of error for the film calibration curve of $3.0\% \pm 3.9\%$ at the 95% confidence level. Also considered is the necessity that as the ^{60}Co source decays with its half life of 5.3 years, the exposure time is accordingly increased, as shown schematically in Figure 7.

SUMMARY

The standardized calibration system as outlined permits one to consistently ascertain that variations in film density introduced by the calibration procedures themselves are negligible. The mobile gamma irradiation device described, using a multi-curie ^{60}Co source, permits a wide range of doses to be obtained with minimal error in their reproducibility.

Figure 1
ORGDP EMPLOYEE SECURITY — METER BADGE

DWG. NO. G-65-644

BLANK

SATURATED

**Date Code
Identification**

Aluminum Shield

Plastic Shield

Cadmium Shield

Open Window

Figure 2
PROCESSED DOSIMETRY FILM

Figure 3
PNEUMATRON
(Schematic)

PHOTO NO. PH-65-1094

Figure 4
PNEUMATRON

DWG. NO. G-65-637

Figure 5
ORGDP FILM CALIBRATION

COBALT - 60 GAMMA (Rads)

EXPOSURE TIME -- 200 Minutes

Figure 6
ORGDP FILM CALIBRATION

Figure 7
ORGDP DOSIMETRY FILM CALIBRATION
COBALT - 60 GAMMA