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CALIBRATION AND FIELD USE OF IONIZATION*
CHAMBER SURVEY INSTRUMENTS

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CALIBRATION AND FIELD USE OF IONIZATION
CHAMBER SURVEY INSTRUMENTS

ABSTRACT

Measurement accuracy of ion chamber survey instruments in field survey situations is affected by both the calibration procedures and the geometric relationship between the radiation source and the chamber. This paper describes the fundamentals of the calibration method used at Hanford for ion chamber instruments, and the resulting capabilities of the instruments in field survey situations. Additional corrections to calibrated instrument results are ordinarily required when measuring small beams, radiation fields associated with large beta sources, and radiation levels where the chamber is in contact with the source. The method of determining the required corrections, and the values of the correction factors are described for one widely-used CP ion chamber survey instrument.

CALIBRATION AND FIELD USE OF IONIZATION CHAMBER SURVEY INSTRUMENTS

W. P. Howell and R. L. Kathren

I. Introduction

Ionization chambers are widely used as detectors in portable radiation monitoring instruments. The advantages of the ion chamber are many, and include wide range, the ability to utilize simple circuitry, and low voltages, and ease of chamber construction, permitting numerous geometries, and the use of air or tissue equivalent walls for minimal energy dependence.

Many ion chamber instruments are affectionately known as "cutie pies", and this phrase has joined other common biological entities - pig and rabbit - in the lexicon of the nuclear world.* The term cutie pie (CP) was originally used to describe ion chamber instruments with a characteristic pistol shape. However, in recent years, the term has been applied to virtually any portable survey meter utilizing a non-pressurized ionization chamber.

This paper will describe the application of a specific cutie pie instrument to field monitoring situations at the Hanford site. After a brief description of the instrument, the actual procedures used in the field will be presented, with particular emphasis given to geometry corrections and measurement of dose rates from mixed beta-photon fields. Finally, the paper will conclude with a discussion of some of the limitations of the Hanford-type cutie pie. While much of the information presented here is specific to a single instrument, an appreciable portion, including the basic concepts, should be applicable to other instruments utilizing similar unpressurized ion chambers.

II. The Hanford CP

The Hanford "Cutie Pie" (Figure 1) is a pistol shaped portable dose rate meter using an ion chamber as a detector. The ion chamber is constructed from a piece of phenolic plastic tubing, 3 in. in diameter and 5.7 in. long, providing an effective chamber volume of 40.2 in.³ (658 cm³). The walls of the chamber are 0.125 in. (440 mg/cm²) thick. As shown in Figure 2, one end of the tubular

* The etymology of the nuclear term cutie pie is obscure. However, the term appears to have originated from a combination of need for security with respect to the use of the instrument and the mathematical symbols Q, t, and π in which Q was charge, t, time, and π , the geometry factor.

FIGURE 1

C.P. Meter
(Model #2209)

chamber butts against the body of the instrument, while the other is fitted with a disc of Mylar or rubber hydrochloride 7 mg/cm^2 thick. A window shield, 440 mg/cm^2 thick, is also provided. All interior surfaces of the chamber are coated with a conductive graphite surface.

A center electrode, 0.125 in. in diameter, runs the full length of the chamber and is utilized for ion collection. With the 658 cm^3 chamber, a dose rate of 1 mR/hr provides 1.4×10^9 ion pairs or a current of about 3×10^{-14} amperes. This is about the minimum level of detection available with a simple electrometer-type circuit. Hence, the instrument has been provided with ranges of 0-50, 0-500, and 0-5,000 mR/hr .

The energy dependence of the Hanford CP in measurement of electromagnetic radiation has been determined by comparison with a free air ionization chamber and NBS calibrated R-meters. Figure 3 shows the results of the study. Above about $150 \text{ KeV}_{\text{Eff}}$, response is essentially flat, irrespective of chamber orientation. Below $150 \text{ KeV}_{\text{Eff}}$, the response rises, peaking at $100 \text{ KeV}_{\text{Eff}}$. At this point, the closed window response is about 40-50% high, relative to 1 MeV . Below this point, response falls, so that at $17 \text{ KeV}_{\text{Eff}}$, the response is about 10% low. While this error is significant, it can be readily corrected, permitting the instrument to be utilized for monitoring the dose rate from bare ^{239}Pu , an important capability at many sites, including Hanford. So important is this particular capability, that it can override numerous other desirable features, including a flatter energy response above $40 \text{ KeV}_{\text{Eff}}$.

Because of the 440 mg/cm^2 wall thickness, beta particles with energies below 1.1 MeV will be excluded from the chamber with the window closed. However, with the window open, the CP will monitor all the betas that would penetrate the dead layer of the skin. Therefore, if suitable corrections are made for geometry, the CP can be used for beta dose rate determinations in the field, as discussed below.

Hanford CP instruments are typically calibrated with a standardized source of ^{226}Ra in equilibrium with daughters.⁽¹⁾ The instrument is checked at three points on all ranges and calibrated to ± 10 , -5% of the true exposure rate. A well calibration system is used, along with a standard positioning jig to ensure reproducible geometry. In addition to the actual calibration, the instrument is driven off scale on all ranges to ensure that it will not fail to respond in a high radiation field.

The importance of a reproducible calibration geometry cannot be too heavily stressed. Many erroneous instrument readings can be directly traced to faulty or inappropriate calibration techniques. However, calibration is not the only factor that affects the use of a dose rate instrument, and the more common serious factors will be considered from the standpoint of field measurements.

FIGURE 3

III. Field Use of the CP

In field survey situations, the four factors which most often introduce errors into ion chamber instrument measurements are chamber energy dependence, variations in source size and instrument to source distance, radiation beams which do not irradiate all of the chamber gas, and chamber limitations on the angular acceptance of beta radiation.

Using the energy dependence curve illustrated in Figure 3 above, meter indications in situations involving gamma or X-ray energies below 150 KeV can be corrected when necessary, if the effective energy of the radiation is known, and if it is monoenergetic. In unknown situations, or those involving a mixture of high and low energies, more sophisticated instruments and methods must be used for dose rate evaluations. For example, very high energy photons might be encountered at an accelerator or reactor, with the predominant photon energies greater than 3 MeV. Under these circumstances, the CP will under-respond, by as much as 50% at commonly encountered energies. In these cases, a method of measuring kerma should be utilized.

All of the other error-causing factors involve some degree of non-uniform ionization of the chamber gas, and meter indications lower than the true dose rate will result. Since the CP is calibrated using radium gammas under conditions which provide a uniform degree of ionization throughout the chamber, the instrument will indicate true dose rates only under survey conditions of a similar nature. Thus, in the case of measurements near the surface of relatively small sources, erroneous readings will occur. Where the error is small, the situation is of little concern, but errors can be as large as a factor of 100 where the situation involves a contact measurement on a small beta source.

The response of the CP instrument under conditions encountered in field monitoring situations has been defined in four separate studies by Hanford personnel.^(2,3,4,5) The first of these was designed to determine true contact dose rates on cylindrical sources, and to provide suitable corrections to instrument readings for these measurements.

The second study was designed to define the angular response of the CP in measurement of extended beta radiation sources. The study covered source to instrument distances between 4 and 36 inches for source diameters between 6 and 72 inches. Correction factors were obtained from the ratio of the total integrated dose rate obtained with the forward axis of the chamber intersecting the center of an incremental source to the total integrated dose rate obtained with the forward axis of the chamber intersecting the center of the integrated source.

The third study was designed to define the actual response and error in measurements of plane circular gamma radiation sources of various radii. Measurements of an incremental source and numerical

integration were used to derive true contact and near contact dose rates. Film dosimeter data supplemented the mathematical calculations. Correction factors were derived for sources having diameters between 0.2 and 144 inches.

The final study was designed to develop a family of correction factor curves for both beta and gamma radiation for all monitoring conditions, utilizing the results of the earlier studies and additional measurements. A small table of the most useful numerical values obtained from the correction factor curves was assembled. Copies were provided to field personnel for attachment to the CP instrument case. Figures 4-6 are the results of these studies.

In field use, the correction factors apply to commonly encountered cylindrical and plane circular sources, radiation beams, and extended beta sources. Since the source diameter may not be readily apparent in a field monitoring situation, the surveyor is often required to scan the area and estimate the source diameter. It should be noted that ambient beta fields, as might be encountered in a room with walls, floors, and ceilings contaminated with a beta emitter can be measured with the CP, utilizing beta field corrections. However, these situations must be evaluated carefully, since the distance from source to detector is variable, and some of the more energetic betas may penetrate the side walls of the chamber. Where the latter occurs, the beta field correction cannot be used.

In a typical field situation, Pacific Northwest Laboratory personnel normally approach an unknown survey situation with the CP window shield open. The following procedure is used in determining the correct dose rate:

1. Determine meter deflections, shield open and shield closed.
2. Determine source size.
3. Apply the appropriate correction factor(s) to the meter deflections, according to the table in Figure 6.
4. The corrected closed shield measurement is the penetrating dose rate (normally only electromagnetic radiation).
5. The difference between the shield open and shield closed meter deflections, when corrected is the non-penetrating dose rate.
6. The sum of the measurements in steps 4 and 5 is the total skin dose rate, including both penetrating and non-penetrating radiation.

This procedure is relatively simple, and has been used successfully by monitoring personnel at Hanford for about ten years.

The Hanford CP, as is true of other instruments of its type, has numerous limitations. However, if intelligently used, the instrument can provide the operational health physicist with reasonably accurate dose rate estimates under field conditions.

CP CORRECTION FACTORS FOR SOURCE SIZE AND DISTANCE EFFECTS
GAMMA PLANE CIRCULAR SOURCES

FIGURE 4

CP CORRECTION FACTORS FOR SOURCE SIZE AND DISTANCE
EFFECTS
BETA PLANE CIRCULAR SOURCES

FIGURE 5

FIGURE 6

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