3.2 IONIZATION CHAMBERS

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3.2.1 SCOPE

This section describes the design, analysis procedures, calibration, and use of pressurized ionization chambers (PIC). These instrument systems are used at EML in the assessment of the penetrating component (gamma plus cosmic-ray secondaries) of the environmental radiation field. Accurate and highly precise measurements of the total exposure rate (or dose rate in air) are made of such sources as:

1. cosmic-ray secondary radiation (high energy muons, photons, and electrons) in the lower atmosphere;

2. natural background radiation from primordial radionuclides (and progeny) in the soil and air;

3. anthropogenic isotopes associated with

    a. direct radiation from nuclear facilities,
    b. gaseous effluents from nuclear operations,
    c. fallout deposition,
    d. residual radioactivity at sites undergoing clean-up.

3.2.2 PIC SYSTEM DESIGN

3.2.2.1 ION CHAMBER

The chamber selected as our standard consists of a 25-cm diameter stainless-steel sphere with a wall thickness of 2.37 g cm^{-2} filled to a pressure of 2.5 MPa (25 atmospheres) with ultrapure argon gas. The collecting electrode is a 5-cm diameter hollow sphere at the center of the chamber supported by a 0.6-cm diameter rod, which in turn is connected to the chamber shell at the center of a triaxial metal-ceramic seal. The middle conductor of this seal serves as a guard ring and is kept at true circuit ground. A 300-V battery is used to provide bias to the outer shell. This voltage along with the large center electrode results in complete charge collection in fields of up to 10 μGy h^{-1}.

Smaller versions of this chamber are also routinely used. They consist of an 18-cm diameter sphere with the same or slightly thicker wall and filling pressures of up to 3.7 MPa. The collecting electrode for these chambers measures 1.9-cm in diameter. Complete charge collection has been observed at 400 μGy h^{-1} with a bias of 300 V.

A complete description of experimental and theoretical investigations involving various PIC designs can be found in De Campo et al. (1972). Known commercial suppliers of these PICs are GE Reuter-Stokes (Twinsburg, Ohio 44087) and LND, Inc. (Oceanside, New York 11572).

3.2.2.2
ELECTROMETER

The ion current from the PIC is measured with a temperature compensated electrometer consisting of a MOSFET (metal oxide semiconductor field effect transistor) and an operational amplifier using 100% negative feedback from the amplifier output to the MOSFET input (Negro et al., 1974). Stable voltage regulators, external to the electrometer, are used to provide power. The electrometer itself is small and light enough to attach directly to the triaxial connector on the PIC and suspend freely without additional support. This arrangement minimizes mechanical stress on the seal insulators and any resultant piezo-electric currents. The response to radiation is about 3 fA per nGy h^{-1} for the large 2.5 MPa chambers and about half that for the 3.7 MPa small chambers. A glass encapsulated tera-ohm carbon resistor used in the feedback loop of the electrometer determines the output sensitivity, generally about 3 mV per nGy h^{-1}, and time response, generally on the order of a few seconds. The electrometer saturates at somewhat over 5 V, which translates to about 1700 nGy h^{-1}.

3.2.2.3
READOUT SYSTEMS

Direct observation of the electrometer output voltage is made with a standard voltmeter. To obtain precise measurements, signal integration is performed by one of two methods listed below.

A. Survey mode.

For real-time results, a voltage-to-frequency converter with scaler and calibrated digital readout is used to provide readings with selectable integration times of 4, 40, or 400 sec. This readout system is generally used with the 18-cm diameter chambers in the form of a two-unit package called a SPICER (small pressurized ionization chamber for environmental radiation; Latner et al., 1983). The system is battery powered and can be either held in hand or tripod mounted. Figure 3.1 shows the system in this latter mode of operation.

B. Monitor mode.

The second read-out method is designed for continuous remote monitoring. It consists of an analog to digital converter, timing and control circuitry, and a magnetic tape cassette recorder (Memodyne, Model 201) housed in a weather proof aluminum box (Cassidy et al., 1974). The ion chamber and electrometer are packaged in a similar box which sits atop the recorder box during operation in the field as shown in Figure 3.2. The standard system records the digitized electrometer output voltage every 10 sec, and is capable of storing up to 17 days of data on a single cassette. Some units have been modified to allow the option of recording every 10, 20 or 40 sec. An alkaline cell battery pack provides power for 8 weeks of operation.

3.2.3 DATA ANALYSIS

The magnetic tape cassette is read out with a Memodyne 3122 ABV reader interfaced to a Hewlett-Packard 9826 computer using a specially developed analysis program (Gogolak, 1982). The analysis procedure is as follows:

1. A 6 h record of the 10-sec data is read into the computer and displayed on a screen.

2. The data is averaged over 5-min intervals, corrected for the zero reading of the electrometer and converted to exposure rate via a chamber specific calibration factor.

3. A printout of the 5-min averages as well as the average over each hour is made. The standard deviation (SD) of the 5-min data for each hour is also computed and printed.

4. Subsequent 6-h records are analyzed and at the end of the tape a summary plot of the hourly data is made. Bad data sections are then edited and a final printout and plot of the corrected hourly average and SD data is obtained. The hourly average maximum and minimum and daily average are also printed for each day along with the average over the entire period.

5. Permanent storage of the corrected 5-min data is made on a diskette.

6. If desired, the data can be analyzed for any dose due to the passage of a plume (Gogolak and Miller, 1974). The analysis routine examines the SD of the 5-min data in each hour and if it is sufficiently high (> 1.7 nGy h^{-1}) it is assumed that a fluctuating plume component was present. A search is then made on each side of the plume hour for the nearest three background hours indicated by a standard deviation that is sufficiently low (< 1 nGy h^{-1}). The average background is computed from these 6 h and subtracted from the total dose in the plume hour to yield the net plume dose.

3.2.4 **CALIBRATION**

Calibration of the PIC is performed using a National Institute of Standards and Technology (NIST) certified sealed 37 MBq ^{226}Ra source and a shadow shield technique (De Campo et al., 1972). The shadow shield method is necessary because it removes the contribution of the room scatter component which we have found to be on the order of 30% of that from the primary beam. At the same time, it also corrects for any other constant factors included in the PIC output such as room background, electrometer zero offset, and α and stress currents. The calibration procedure is as follows:

1. The source is placed in a low mass holder at a height of about 1 m above the floor and at a distance of 4, 5, or 6 m to the PIC (geometric center), which is at the same height on a low mass stand.

2. A 30-cm thick lead shield with a cross section measuring 10-x-10 cm is interposed on a low mass stand so as to intercept all primary rays from the source to all parts of the PIC through the full thickness of the shield. Alignment is checked with a string with a dummy source in place. Slight overshielding (a larger shadow) on the order of 1-2 cm is used as this results in a negligible error as opposed to undershielding which could produce a significant error. The use of a shield with a cross section that is roughly half that of the PIC is recommended because the shadow size cast will require the shield to be placed near the midpoint between the source and the PIC thus minimizing the production and interception of lead fluorescent X-rays and also allowing a proper alignment which is not too critical to shield placement.

3. The source is placed in its holder and the output signal of the PIC is averaged over a 10- to 30-min time period.

4. The lead shield is removed (leaving its stand in place so as to change the scattering conditions as little as possible), and the PIC output signal is averaged again over a 10- to 30-min period.

5. The difference between the average signals (reading with shield not in place minus reading with shield in place) is divided by the exposure rate delivered by the source at that distance to yield the Ra primary beam calibration factor. This calibration factor must be adjusted by a small amount for the energy spectrum that will be encountered for a particular radiation field. For our standard 25 cm-2.5 MPa chamber, this correction yields a 3% higher sensitivity for a normal background radiation field, while for the 18 cm-3.7 MPa chamber it is 1% higher.

6. Background readings are taken in the calibration room and in a whole body counter in both the negative and positive high voltage modes of operation to verify that the system does not have stress currents present and that there is no high internal background.

3.2.5 INFERRING EXPOSURE (DOSE) RATE

The total PIC current can be expressed as

$$R = k_c I_c + k_t I_t + R'$$

where

k_c = the calibration factor for cosmic radiation
I_c = the cosmic radiation exposure rate
k_t = the calibration factor for terrestrial radiation
I_t = the terrestrial radiation exposure rate
R' = the α particle current from contamination in the steel shell (~2 fA for the 25-cm chamber and 1 fA for the 18-cm chamber)

For our standard chamber, the values of k_c and k_t are only 1% different so that for most applications the total exposure rate ($I_c + I_t$) is inferred by simply subtracting the α current from the total current and dividing by the factor corresponding to the dominant component of the radiation field. (In a strict sense, the quantity "exposure rate" is only applied to γ rays of certain energies. However, for environmental radiation fields it is convenient to extend the meaning to include the exposure rate equivalent of ionization in free air due to cosmic rays.) For expressing the exposure rate in SI units, the appropriate quantity would be C kg^{-1} s^{-1} or A kg^{-1}. Since this is a rather unfamiliar unit, we prefer to convert the exposure rate to dose rate in air when reporting data in SI units.

A more accurate estimate of I_t is derived by substituting a value for I_c in the above equation. To do this, the altitude of a measurement site is determined using a topographical map or the barometric pressure is measured. The corresponding cosmic-ray exposure rate (dose rate in air) is inferred using the data presented in Figure 3.3. It should be noted that I_c will vary with the 11 year solar cycle, being a few percent higher (lower) at solar minimum (maximum) (O'Brien, 1972).

Although not common with the small freely suspended MOSFET electrometer, stress currents can result from mechanical pressure on the ionization chamber insulator. The presence of these unidirectional currents is checked by reversing the high voltage polarity on the ion chamber shell. After correcting for the electrometer zero offset, the readings should agree if no stress current is present. If the readings do differ, the true reading is just the arithmetic average of the two.

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Figure 3.1. SPICER system set up for field measurements showing a tripod mounted ion chamber with an electrometer unit connected via cable to the digital readout box.

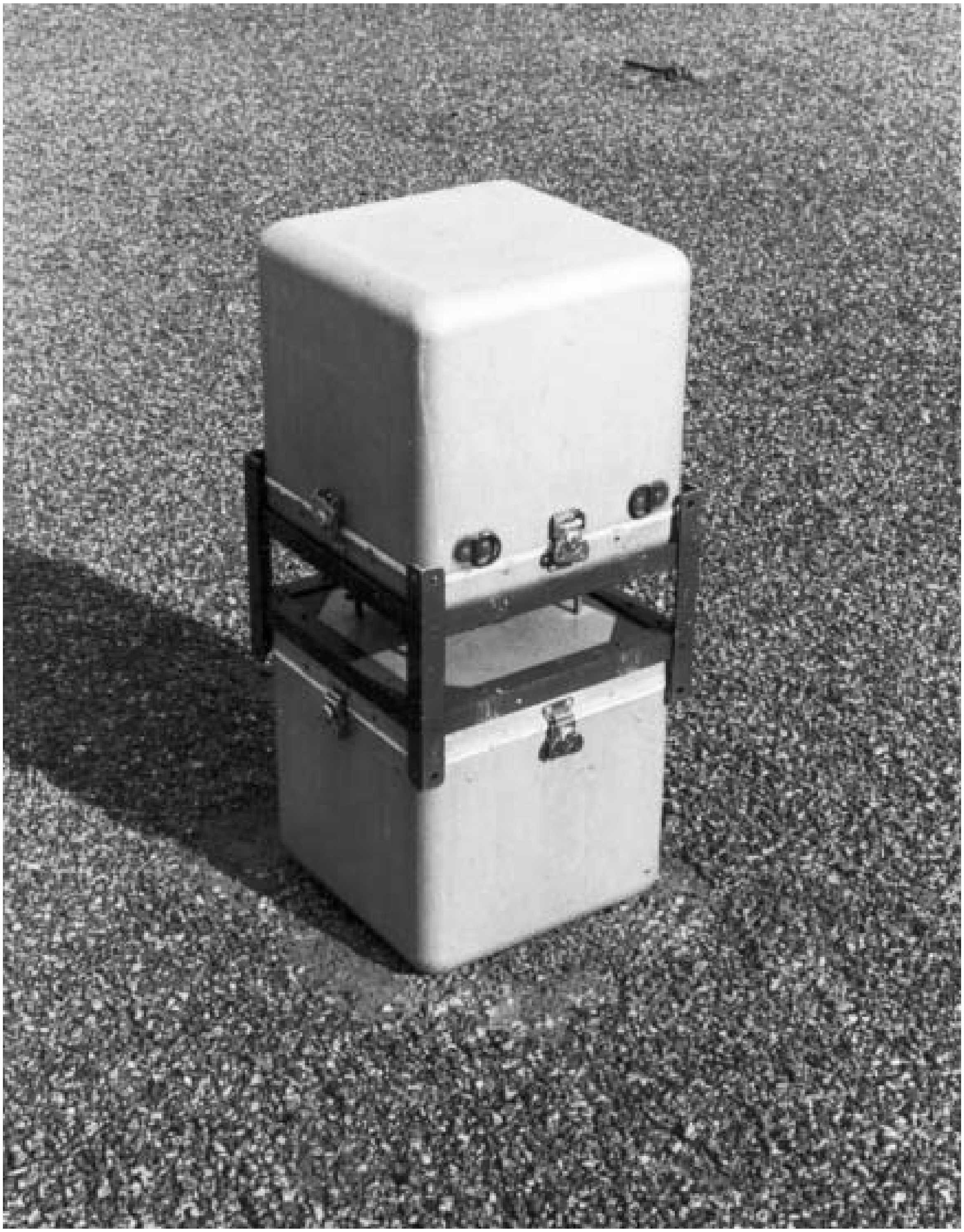

Figure 3.2 PIC system for field monitoring. The chamber and electrometer are housed in the top box, and the digital recorder unit is contained in the bottom box.

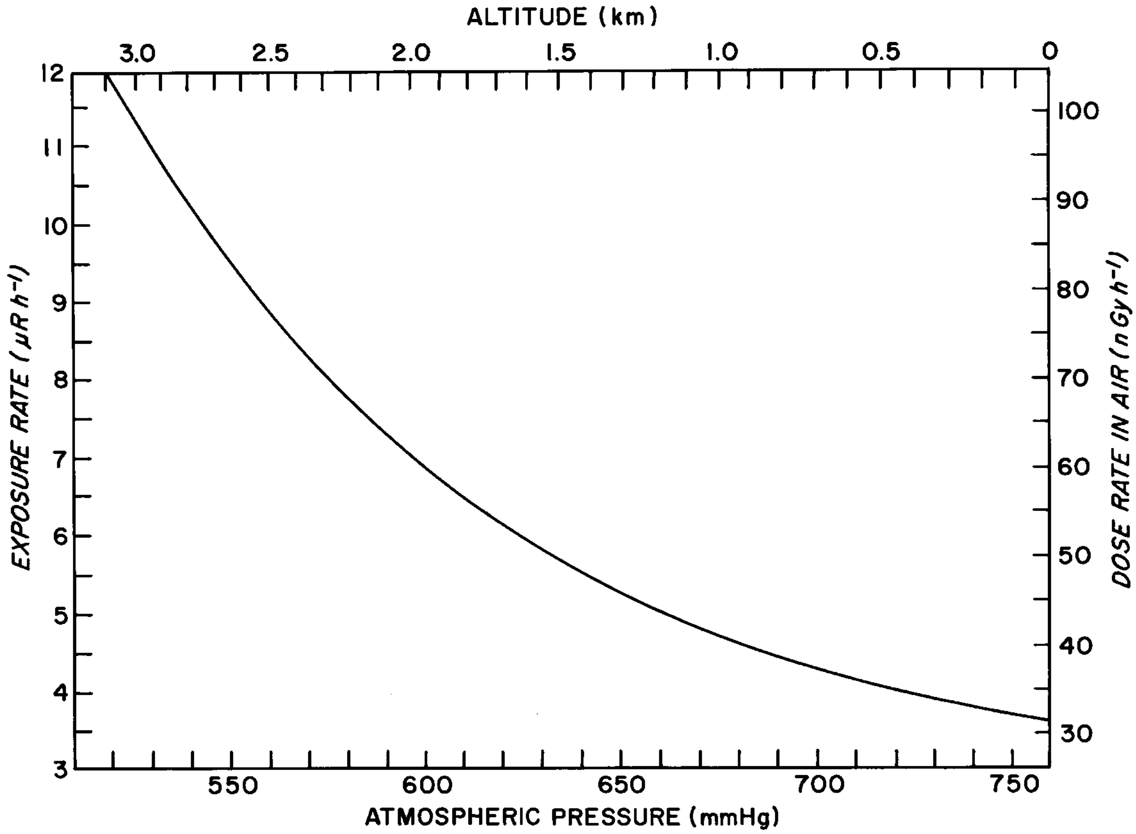

Figure 3.3 Cosmic-ray exposure rate equivalent and dose rate in air as a function of atmospheric pressure and altitude for mid-latitude.