DESIGN AND PERFORMANCE OF MAJOR BODY MONITORING FACILITIES

A. Knight, F.A. Fry, P.D.J. Whetmath and M.C. O'Riordan
National Radiological Protection Board, Harwell,
Didcot, Oxon, United Kingdom

ABSTRACT

A description is given of major body-monitoring facilities recently installed in a new laboratory complex. They include a whole-body monitor, a low-energy photon monitor and associated electronic and data-processing equipment.

Careful selection procedures for the laboratory construction materials ensure low background. The effect of the main steel shield is documented in terms of Background Index together with the effect of the gradual addition of graded lining.

Details are provided of the control system for the whole-body monitor, including live time scan regulation and the reduction of end effects. The low-energy photon monitor, an array of dual phosphor detectors intended mainly for determining transuranic nuclides in lungs, is also described along with the pulse-shape analysis technique for background reduction. Difficulties such as subject background and tissue attenuation with incorporated nuclides that emit low-energy photons are discussed.

An account is provided of the control data-processing system which uses CAMAC and a small computer and to which several other spectrometric detectors are input.

Performance data of the equipment are briefly described.

1. INTRODUCTION

The body-monitoring facilities described in this paper were installed recently in the new headquarters building of the National Radiological Protection Board (NRPB) at Harwell. They replace the facilities (1) in the NRPB's former laboratories at Sutton where body monitoring was carried out by the Radiological Protection Service and by NRPB for nearly 20 years.

2. RADIATION BACKGROUND

The building materials used in the relevant part of the new building were specially selected for low radioactivity. Flint lime bricks made from Thames Valley aggregate are used. ^{40}K, ^{226}Ra and ^{232}Th levels in these bricks, which are also quite dense, are very much lower than the levels in alternative materials such as clay bricks or lightweight aggregate blocks (2).

The equipment is installed in a room constructed mainly from aged naval steel. The internal dimensions of the room are 4.8 m x 2.2 m x 2.0 m high. The steel is 15.2 cm thick except for the base which is 20.3 cm thick. The inside of the room is lined with 1 cm of aged lead and 0.2 cm of steel which successively absorb scattered and characteristic radiation. During and after construction, the Background Index (defined as the counts per minute per cm^3 of NaI (Tl) crystal over the energy range 0.1 - 2 MeV) was measured. The following results are for a 15.2 cm diameter x 10.2 cm thick NaI (Tl) crystal, although some of the measurements were made with a smaller crystal and a volume correction applied (3). Background Index values were 0.39 for the bare steel room, 0.29 for the room lined with lead, 0.31 for the room lined with lead and steel and 0.34 for the completed room with equipment. Although the inner steel resulted in an increase in Background Index as defined above the background decreased by approximately the same relative amount in the low energy region of interest below 0.1 MeV.

Approximate radon daughter levels inside the steel room are 0.1 pCi/l RaA (^{218}Po), 0.01 pCi/l RaB (^{214}Pb) and 0.002 pCi/l RaC (^{214}Bi). A filtered recirculating air system is used which provides 10 changes of air per hour and a make-up of up to 15% of fresh air. A constant temperature of 21°C is maintained in the steel room.

3. WHOLE-BODY MONITOR

The whole-body monitor is a scanning-bed type in which the bed moves on rails through a fixed steel ring of effective diameter 1 m. Six detectors, each consisting of a 12.7 cm diameter x 10.2 cm thick NaI (Tl) crystal and EMI 9530B photomultiplier tube, are mounted at 0°, 45°, 135°, 180°, 225° and 315° around the ring from the vertical. Each detector can be moved radially so that its face is between 10 and 35 cm from the mid-line through the centre of the ring. Each detector can also be angled up to ± 10° from the radial direction. All detectors can be fitted with easily detachable 2.5 cm thick aged-lead side shields. Profile scanning is possible by fitting the crystals at 0° and 180° with a further 2.5 cm thick side shield and also a 5 cm thick front shield with a single slit into which shaped slugs may be inserted.

The bed is driven by a drive shaft from a stepping motor. At present a linear scan is used. Scanning time can be varied, but is normally set at 30 minutes real time. There are two possible sources of error with this arrangement: lost counts due to a possible high dead time and non-uniformity of response. Dead time can be high due to the activity of the source under consideration, or because of simultaneous high count rate inputs to the data processing system described below, or because of other operations using this system. It is therefore desirable to control the speed of scan in live rather than real time.

The advantage of using a scanning system is that it is possible to obtain a response with reduced dependence on the distribution of the radioactivity within the body (4). With a constant scanning speed, however, end-effect errors occur. For example, the response to a point source falls to approximately 60% of its maximum value when the source is placed 90 cm from the centre of the bed. This can be corrected by varying the speed of scan during the scan to compensate for the reduced response.

A system for controlling the speed of scan in live time and for varying the speed is described below.

4. LOW ENERGY PHOTON MONITOR

For the detection of low energy (10 - 100 keV) photon emitters in the body, for example plutonium in lung, dual phosphors similar in principle to those first used by Laurer and Eisenbud (5) are used. The system uses four commercially available dual phosphor detectors 127 mm in diameter, each with a 0.2 mm beryllium window and consisting of a 1.5 mm thick NaI (Tl) crystal optically coupled to a 51 mm thick CsI (Tl) crystal. This array of detectors is suspended from the ceiling of the steel room. A number of adjustments are provided so that detectors can be positioned closely above the body of the person being measured. The outputs of the 4 detectors are normally coupled in pairs, one pair viewing the upper areas of the lung, the other the lower areas.

Use is made of the difference in scintillation decay time of the 2 scintillators (250 ns for NaI (Tl) and 1000 ns for CsI (Tl)) to obtain a lower background in the energy region of interest by means of pulse shape analysis. Low-energy photons are totally absorbed in the thin crystal. Most higher energy unwanted photons penetrate the thin crystal, losing some energy in the process, and then interact with the CsI (Tl) crystal. The signal due to the low energy radiation will thus have the characteristic decay of NaI (Tl), and the signal due to extraneous high energy radiation will have a decay time which is mainly characteristic of CsI (Tl).

In brief, the pulse shape analysis system operates as follows. The photomultiplier signal is processed by a delay line shaping amplifier the output of which is fed into an ORTEC 458 pulse shape analyser. This is set to generate a logic pulse when a photon interaction has occurred only in the NaI (Tl) crystal. This logic pulse then opens a linear gate to allow analysis by the data processing equipment. Typical backgrounds with no subject in position range from 1.5 to 3 counts per minute for each of the various detectors in the energy region 12 - 25 keV.

For in vivo measurements, the background will vary from subject to subject depending upon body build and the amount of ^{40}K or of any other radionuclide in the body. A library of background spectra is being compiled using unexposed persons of different body build whose ^{137}Cs and ^{40}K contents are also being measured.

Analysis of results is further complicated by the absorption of low-energy photons within the body: for example, the half-value thickness in tissue for photons from ^{239}Pu is only 0.6 cm. A chest phanton with a large rib cage and variable wall thicknesses of tissue-equivalent material is being developed for calibration purposes and is the subject of another paper at this Congress (6).

5. DATA PROCESSING AND CONTROL SYSTEM

Signals from either the whole-body detectors or the low-energy photon detectors are fed to a CAMAC interface system under the control of a PDP 11/05 digital computer. The CAMAC system is provided with 8 separate analogue inputs which are routed via an 8 input mixer unit. An analogue signal from the mixer unit is fed to an analogue to digital converter (ADC) which has a resolution of 1024 channels and a 16 MHz clock rate. The mixer unit not only provides a single analogue output but also provides routing signals which are fed on to the CAMAC data highway in order that each analogue signal can be stored in a different part of the computer store. The PDP 11/05 computer has a 16k word store which is shortly to be increased to 24k, and is under the control of an operator through a teletype writer console. Further data storage and programming facilities are being provided by means of a dual flexible disc unit. Output and input facilities to and from paper tape are provided.

The movement of the scanning bed is to be controlled via CAMAC as discussed above. The speed of the stepping motor and hence of the bed will be controlled through the CAMAC data highway by means of a suitable programme stored in the computer. This will enable a single scan to be made at a constant speed (linear scan) or to be divided into a maximum of 16 different speeds (from zero up to 60 cm per minute) to accomplish the necessary velocity profile for end effect correction. Use will be made of the 1 MHz CAMAC clock to provide a basic oscillator to drive the stepping motor. Dead time correction will be accomplished by means of the "BUSY" signal from the ADC which will be used to halt the bed drive temporarily while the ADC is processing a photon event.

6. PERFORMANCE DATA

Installation of the facilities described in this paper commenced in 1975; purchasing and commissioning of some parts of the data processing and control system are still taking place. Some preliminary performance data may however be of interest.

The low energy photon monitor has been installed for only a short time, and so far, most measurements on subjects have been to provide background spectra. Some measurements are also being performed on NRPB staff occupationally exposed to aerosols containing ^{238}Pu and ^{241}Am, but because of the early stage of development of the calibration phantom (6) it is not yet possible to quote a value for the minimum detectable activity (MDA).

The whole-body monitor, which was operational first, has been used for the assessment of body radioactivity in persons accidentally exposed to several radioactive materials including radium, thorium, uranium and ^{88}Y. NRPB staff have been measured to provide calibration data for the low-energy photon monitor and to measure ^{137}Cs levels. Typical MDAs, defined as twice the standard deviation of the background count over the background, for a 30 minute scan are 0.6 nCi of ^{137}Cs for a uniform distribution in the body and 1 nCi of retained ^{228}Th for a uniform distribution in bone.

REFERENCES

(1) UK 3.2 and UK 3.3. Directory of whole-body radioactivity monitors (1970 edition). IAEA, Vienna (1970).

(2) HAMILTON, E.I., Am Ind Hyg. Ass. J. 32 (1971) 398-403

(3) COURBOIS, Th., et al., Nucl. Instr. and Meth. 69 (1969) 93-100

(4) PALMER, H.E., ROESCH, W.C., Health Phys. 11 (1965) 1213-1219

(5) LAURER, G.R., EISENBUD, M., in proceedings of symposium on Diagnosis and treatment of deposited radionuclides, Excerpta Medica Foundation (1968) 189-207

(6) FRY, F.A., GREEN, B.M.R., KNIGHT, A., WHITE, D.R. "A realistic chest phantom for the assessment of low energy photon emitters in human lungs" these proceedings.