AN INEXPENSIVE LIGHTWEIGHT ENVIRONMENTAL SURVEY INSTRUMENT

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Abstract

The operation of power producing nuclear reactors in the U.K. involves a statutory requirement to measure radiation levels in the area surrounding each nuclear site. The natural radiation background is measured at specified locations prior to operation of the reactor and afterwards routinely every three months. A survey instrument used for such measurements must therefore measure exposure levels from background (typically a few $\mu R.h^{-1}$ in the U.K.) upwards. Other requirements for the instrument are that it should be very portable, be capable of being read accurately at low exposure rates, and should maintain its calibration.

The instrument described in this report weighs only 10 lbs, has a good energy response, ± 15% over the range 50 keV to 6 MeV, and measures exposure levels from a few $\mu R.h^{-1}$ to 100 $mR.h^{-1}$. Ambiguities resulting from reading a fluctuating meter needle at low exposure rates are overcome by integrating the count over a preselected time, digital readout being provided. The report describes a comprehensive evaluation of the instrument and its comparison with other commercially used instruments. The instrument price is considerably cheaper than that of comparable instruments.

Introduction

Measurement of gamma radiation in the environment, natural prior to the operation of a power reactor and afterwards natural plus that due to the reactor, requires an instrument that records levels from a few $\mu R.h^{-1}$ upwards. As the spectral content of this radiation may be unknown the exposure rate response of the instrument should be as flat as possible over a wide energy range, say 30 keV to 7 MeV.

Portable survey instruments used by the C.E.G.B. for this work indicate the measured exposure rate by means of a moving coil meter display.[1] The reading of such meters at low exposure rates involves problems of interpretation where a needle is fluctuating over a significant range of readings.

Recent advances in electronics have made it possible to produce small portable scalers with digital readout. In addition energy compensating filters are now commonly used to improve the poor energy characteristics of G.M. counters. To keep the total cost low, the instrument described in this report makes use of a commercially available portable scaler, G.M. circuitry and energy compensated G.M. counters.

Instrument Description

Four energy compensated G.M. counters, 20th Century type B6T's, are mounted radially on a tripod (Fig.1) to give the best directional response and to enable measurements to be made at 1 metre above ground. A short co-axial cable connects the detectors to the input of the electronics.

The electronics consist of the amplifier and E.H.T. unit of a Mini Monitor Mark V, and a Mini Instruments portable scaler type MS6.10. Both these units are housed in a small metal case, 20 cm x 14 cm x 12½ cm. Although the instrument is intended for outdoor use no special seals were fitted to the prototype to make it waterproof. During field trials a large polythene bag was slipped over the detectors and electronics and the measurements on Trawsfynydd Lake during a wet day and on rough water showed this to be adequate protection. Power supplies to the G.M. amplifier and E.H.T. unit are from two 9 volt batteries type PP6. The scaler unit is powered by four 6 ampere-hour Nickel-Cadmium rechargeable batteries and will run up to 10 hours continuously on a single charge.

Each G.M. counter was connected separately and its operating voltage plateau determined. The plateau was also measured with all four counters connected to verify that the same voltage range was obtained and the operating voltage for the counters was set at 680 volts.

Evaluation of Instrument

Laboratory Tests

Energy Response

The photon energy spectrum of a measured radiation field is frequently unknown and therefore an environmental survey instrument is required to have a 'flat' response over a wide energy range. Many reactors produce significant amounts of 6 MeV gamma radiation, and in gas cooled reactors this arises from the ^{16}O excited state which is formed by the fast neutron capture in ^{16}O of the CO_2 cooling gas and the subsequent beta decay of ^{16}N to $^{16}O^*$.

Tests were made at 29, 47, 59, 85, 107, 147, 183 and 210 keV using an improved low exposure-rate, filtered, X-ray series whose spectra have resolutions of 20%.

Radionuclide sources were used to measure the response above 200 keV up to 1.33 MeV.

The 335 keV resonance of the $^{19}F(p,\alpha\gamma)^{16}O$ reaction was used to determine the 6 MeV response, the radiation field being standardised by associated particle counting of the alpha particles with cross-checks by ionization measurements.

Fig.2 shows the energy response obtained. The response expressed as instrument reading divided by standardised exposure-rate is plotted against photon energy and has been normalised at 0.8 MeV.

Linearity of Response

Linearity was tested with standard ^{226}Ra sources and ^{60}Co sources. Results are given in Fig.3 and show that the instrument has a linear response up to 10 $mR.h^{-1}$. Although the response is non-linear above this exposure rate no fall-back effects are observed until about 4 $R.h^{-1}$ and at approximately 100 $R.h^{-1}$ the reading has reduced by 20% compared to that at 4 $R.h^{-1}$. The meter reading, however, still remains greater than full scale for exposure rates up to 100 R.h^{-1}. The apparent non-linearity below 20 μR.h^{-1} is discussed later on.

Temperature Tests

As the instrument will be used outdoors throughout the year it is important that its response should not change significantly with expected variations in temperature.

The instrument was placed in an environmental cabinet and irradiated in a constant field from a ^{60}Co source, the temperature was varied over the range -20°C to +50°C. Before commencing these tests new 9 volt batteries were fitted and the Ni-Cd batteries were re-charged. The readings remained constant within 109.0 cps ±7 cps over this temperature range except at +50°C where a reading of 136 cps was obtained.

Variations in Instrument Readings with Supply Voltage

Tests were made to measure the variation in instrument reading with change in supply voltage for both battery supplies, the instrument being irradiated in a constant field. The lower limit markings for both battery tests were perfectly adequate.

Field Tests

Measurements were made at normal 'district survey' locations at two nuclear power stations.[2] Exposure rates were measured with the instrument and with other commonly used low exposure-rate instruments. The other instruments used in the comparison were the BNL 1 which has a plastic phosphor detector and a bottom range of 0-30 μR.h^{-1}, and the A.E.R.E. type 1368A which has 4 G.M. counters, 3 used in parallel for the lower ranges, and a bottom range of 0-50 μR.h^{-1}. For two of the locations measurements were also made with the Nuclear Enterprises N2601, which has an energy compensated G.M. counter and a single log range of 0 - 10 mR.h^{-1}, and with the General Radiological 1597A which uses a NaI detector and has a bottom range of 0 - 30 μR.h^{-1}. All the instruments had been previously calibrated against ^{226}Ra sources and the readings taken were all corrected for any non-linearities.

The first measurements were made at Trawsfynydd Lake, close to the Nuclear Power Station which was not operating at the time. Four sets of measurements were made above water depths between 20 to 30 feet and the following averaged results were obtained. Prototype background monitor 4 μR.h^{-1}, BNL 1 instrument 5 μR.h^{-1} and 1368A instrument 7.5 μR.h^{-1}.

A second series of measurements were made at another station, with the reactors on load. Two different one mile locations were selected at which the results in Table 1 were obtained. Each reading for the meter display instruments was obtained by observing the needle for approximately one minute and taking the average reading, the figures in brackets show the range of fluctuations of the instantaneous reading.

Table 1

Instrument Type	Corrected Instrument Reading for 1 mile locations in $\mu R.h^{-1}$	
	Location 1	Location 2
Prototype background monitor	11	10.2
BNL 1	9(7 to 11.3)	8(6.5 to 10.2)
1368A	11.5(10 to 12)	11(10 to 11.7)
1597A	13(10.7 to 15.3)	10(8.5 to 11.5)
2601	12(9.5 to 17.3)	11.5(6.5 to 19.5)

The following conclusions have been made from these comparisons. Accurate assessment of very low exposure rate levels is difficult and differences of only 1 $\mu R.h^{-1}$ between different instruments must be considered good. Measurements on Trawsfynydd Lake were made at lower exposure rate levels than the background radiation level of the room used for instrument calibration and corrections for non-linearity have therefore been obtained from extrapolation. No standard instrument will measure levels in the $\mu R.h^{-1}$ region and hence no accurate measurement can be made of the calibration room background level. The assumed value of 6.5 $\mu R.h^{-1}$ is an averaged extrapolated result of measurements made in this room with a large number of different instruments of several types. Uncertainty in the absolute value of the room background may contribute to non-linearity of the prototype below 20 $\mu R.h^{-1}$(Fig. 3).

For the Lake measurements the radiation field is principally due to cosmic radiation with a small contribution from any radioactive content in the Lake. Levels of about 3.5 $\mu R.h^{-1}$ are normally reported for cosmic radiation and so the readings of 4 $\mu R.h^{-1}$ for the prototype and 5 $\mu R.h^{-1}$ for the BNL 1 instrument appear realistic values.[3] The reading of the 1368A is just over double the cosmic radiation level and may be due in part to the built-in radioactive content of the detectors. This built-in activity would be allowed for in setting the instrument up at 6.5 $\mu R.h^{-1}$ but would cause it to read high if it were placed in a lower level radiation field.

Looking at the results for the other station it is interesting to see the large variations in readings obtained. For the one mile locations the BNL 1 instrument gave lower results than for all the other types. The 2601 instrument readings were approximately 1 $\mu R.h^{-1}$ higher than the prototype results, this good agreement is not too surprising since the 2601 uses a single G.M. tube which is identical to the 4 detectors used in the prototype. The large fluctuations in the 2601 readings are due to the poor statistics obtained by using a single small detector. At these 1 mile locations the prototype and the 1368A are in good agreement and apart from location 1, so is the 1597A.

Conclusions

The tests on the prototype environmental survey monitor have shown that it compares favourably with other commercial low-level instruments whilst not having the interpretation problems associated with a meter display. The instrument has a good energy response (± 15% for 34 keV to 6 MeV), is simple and easy to use, and will cost approximately £280 (∿ $670).

The environmental monitor described is only a prototype and a number of changes will be introduced in the operational instrument, for example the controls will be simplified and the meter markings altered to $\mu R.h^{-1}$.

Many of the differences in readings observed when using different types of instruments arise from the problems of calibrating instruments at a few $\mu R.h^{-1}$ and further investigations are required on the calibration techniques and standardisation at these radiation levels.

Acknowledgements

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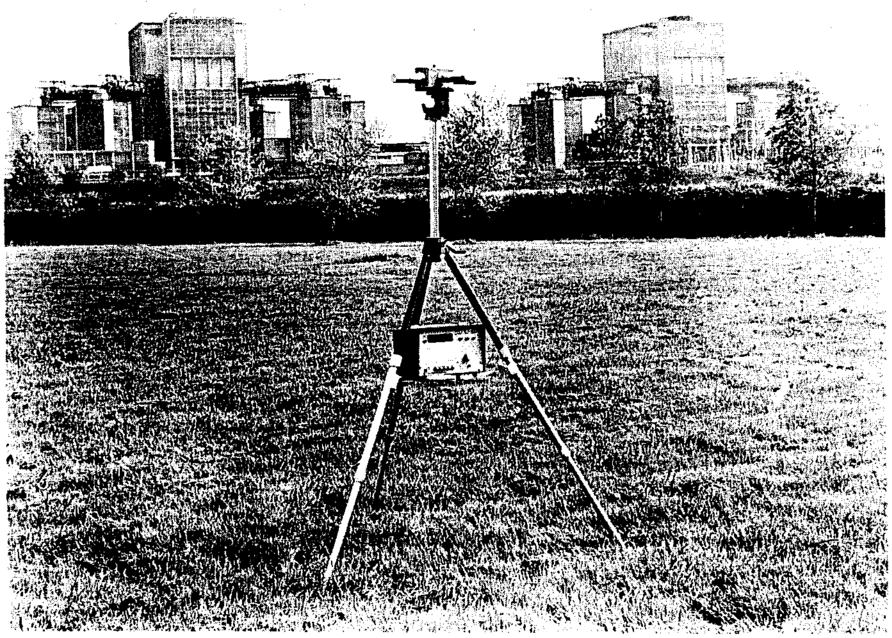

Fig.1 Lightweight Environmental Survey Meter

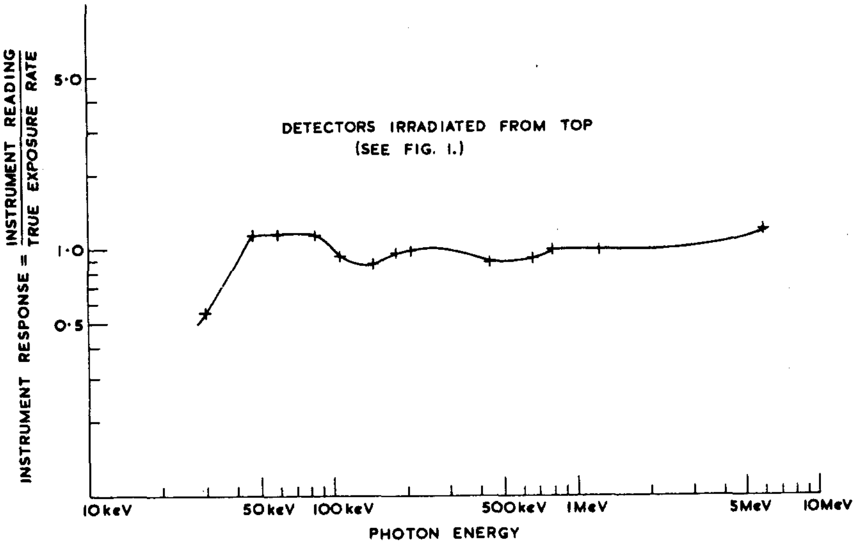

FIG. 2. PHOTON ENERGY RESPONSE.

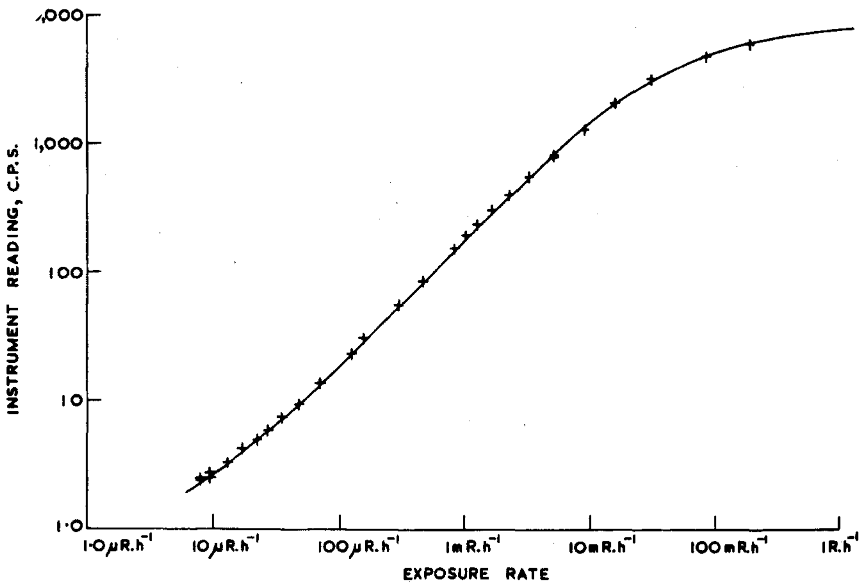

FIG. 3. LINEARITY OF BACKGROUND MONITOR.