SELECTION CRITERIA FOR DETECTORS FOR ENVIRONMENTAL DOSERATE MEASUREMENTS AROUND NUCLEAR INSTALLATIONS

Rupprecht Maushart
Laboratorium Prof. Dr. Berthold, Wildbad/F.R.G.

Introduction

The external exposures to the population in the vicinity of nuclear facilities by airborne radioactive effluents can be assessed, with a detection limit of some 10 μSv per year above background, by long-term measurements using TLD dosimeters (1). This is done today routinely around most nuclear power plants in the western world.

The information gained from such measurements, however, is not readily or momentarily attainable. Furthermore, it will come much too late in case of abnormal or accidental emissions, to derive any recommendations or even measures for preventive dose reduction.

Consequently, many countries exploiting nuclear power have issued regulations for doserate measuring stations to be operated around nuclear reactor sites(2,3). The stations may be set up at the site boundaries, or, preferably, in the midst of settlements in the neighbourhood of the site.

The main point is that the measured values are transferred directly to a central control station where the data are available at any time. The control station doesn't necessarily need to be located at the reactor itself. It will be, in many cases, operated by the local public safety authorities.

In establishing performance criteria for such environmental doserate measuring networks, many aspects have to be taken into consideration. The most incisive decision, however, is the choice of a suitable detector because, in spite of all progress achieved with modern electronics and microprocessors, it is still the detector that determines the essential characteristics of the system.

It is the aim of the following contribution to specify some important requirements, and to suggest detectors meeting them.

Detector Requirements

The requirements influencing the selection of detectors cover: doserate range and accuracy of lower doserate measurements; energy range; directional dependence; temperature dependence; long-term stability and detector lifetime; economy. Several standards or guidelines relating to environmental gamma ray doserate measurements have been published in the last years (4,5,6,7). However, their specifications, on the one hand, differ widely, and on the other hand do not take into account all of the relevant points enumerated above. A comparison has been given in (8), and the major conclusions will be discussed here.

The external doserate caused by the natural terrestrial, atmospheric and cosmic background radiation, is assumed to be about 0.1 μSvh^{-1}. There are, however, many regions where it is considerably less. The requirements, with respect to the lower measuring range, vary between 0.1 and 0.01 μSvh^{-1}, however in most cases without specifying what the statistical accuracy of the measurement shall be, and what measuring times are acceptable to achieve this limits.

By combining and averaging the various requirements, we arrive at 0.04 μSv h^{-1} to be assessed within ± 10%, single statistical standard error, and for 60 s measuring time. Less stringent requirements of 0.1 μSvh^{-1} within 3600 s are applied for measurements used only for accident monitoring.

The upper limit of the measuring range is not clearly defined in the specifications either. In practice a value between 1 and 10 Svh^{-1} has been adopted bearing in mind incident monitoring. Two detectors are then necessary and sufficient for covering the entire range.

The next important feature is the energy range of the detector. Most standards state 50 keV as the lower edge, with a tolerable deviation between 25% and 40% from the indication at 662 keV. 50 keV seems to be a compromise between the technical possibilities of usual detector systems and the necessities of the measurement. It has been shown that in case of Xe-133 emission, which is a comparatively likely event, approx. 60% of the exposure rate from the cloud is due to energies lower than 50 keV (9). Therefore, detectors would be preferable with an energy range down to about 30 keV - 25 keV.

The requirements for the upper energy range limit vary between 1.3 MeV and 3 MeV. This, however, is no great issue because most detectors are oversensitive in this range anyway.

With regard to directional dependence, an average sensitivity is asked for over the full sphere that is not lower than 70% of that in the most sensitive direction, again referring to 662 keV.

Primarily in the English-speaking countries, there are also requirements for detector arrangements which are screened against the lower hemisphere, i.e. have an extremely asymmetrical response distribution in favour of the upper hemisphere. This lowers the background value and improves the detection limit for cloud radiation. However, this arrangement seems unrealistic for general assessment of human exposure dose. Man is not screened against the lower hemisphere either.

The range of temperature independence requirements begins at -25°C and ends at +50°C, with an acceptable deviation of ± 50%.

When a good long-term accuracy must be obtained, a low temperature dependence is an absolute must. An error span of ± 50% seems totally unacceptable. It is not technologically determined either since there are better detectors.

For the upper temperature limit 50°C is often not enough since temperatures up to 70°C can be reached in the probe when the detector is mounted outside and the sun shines.

However, when determining the temperature dependence, it should be taken into account, that all components mounted out of doors, i.e. preamplifiers etc. must be included in the test. They may constitute the factor determining the deviation.

Detector Performance

All detector types used so far for environmental monitoring - ionisation chamber, scintillation counter and counter tube - have their strengths and weaknesses. Judged by the requirements discussed in this paper and by the current state of the art, however proportional counter tubes of modern design are particularly well suited.

To obtain the lower detection limits referred to above, with a pulse-generating detector, a response of the probe is required of at least 42 s^{-1} (sensitive measurement) or 0.35 s^{-1} (accident measurement) per 1 µSh^{-1}. The statistical error of the signal from high-pressure ionisation chambers as used today for environmental monitoring corresponds roughly to that of a counter tube with 40 s^{-1} per 1 µSvh^{-1}. There are, however, proportional counter tubes being applied already for high-precision low-level doserate measurements which produce a countrate of more than 200 s^{-1} per 1 µSvh^{-1} (10).

Another problem nevertheless arises when natural background doserates are to be measured with a high degree of accuracy. Part of the natural background is cosmic radiation, the hard component of it amounting to about 0.03 µSvh^{-1} at sea level and more at higher elevations. Detectors, however, are calibrated at much higher doserates and usually with 662 keV gamma radiation. They may show a very different doserate response for the very high cosmic energies. It has, in fact, been observed that different detector systems may give background readings differing by a factor of two or more, even if they have been thoroughly calibrated in the upper dose range (12). Measures to be taken have been proposed in (11).

Since counter tubes produce a digital signal, they demand much less in terms of stability from the associated electronics than ionisation chambers or scintillation counters with analog signal outputs. Compared to GM counter tubes, proportional counter tubes have a considerably longer life.

Scintillation counters, on the other hand, suffer from a relatively high temperature dependence that has to be compensated for to achieve acceptable results.

It is possible to build proportional counter tubes where the influence of temperature is virtually zero between -20°C and +70°C.

In the following table, the performance figures of doserate and energy dependence are given for two newly developed detectors, covering together a doserate range from 10^{-8} Svh^{-1} to 5 x 10^{0} Svh^{-1}. HV supply and amplifier are integrated in the probes, and pulses may be transferred by suitable cables, over distances of several km.

	Proportional counter tubes		Remarks
	LB 6121 High-doserate probe	LB 6123 Low-doserate probe	
External dimensions	12 mm ø x 96 mm	53 mm ø x 400 mm	without HV/preampl.
Calibration factor	4x10^2 s^{-1} per 1 mSvh^{-1}	4x10^4 s^{-1} per 1 mSvh^{-1}	
Lower doserate range	4 µSvh^{-1}	0.04 µSvh^{-1}	within ± 10% 1σ, 60 s
Upper doserate range	1 Svh^{-1}	5 mSvh^{-1}	10% deviation from linearity
Energy range	50 keV - 2 MeV	40 keV - 2 MeV	within ± 40% from 662 keV
Temperature range	-20°C - +70°C	-20°C - +70°C	within ± 10%, including preampl.
Detector lifetime	> 5 years	> 5 years	

References

1. J. Czarnecki, M. Baggenstos, J. Schuler, H. Völkle; Eine Methode zur Auswertung von Messresultaten der Umgebungsüberwachung von Kernkraftwerken mit Thermolumineszensdosimetern.
   An evaluation method for TLD-results from dose measurements around nuclear power plants. In: Radiologische Auswirkungen von Kernkraftwerken und anderen kerntechnischen Anlagen auf den Menschen und seine Umwelt. FS-82-27-T (1982).

2. Richtlinie zur Emissions-und Immissionsüberwachung kerntechnischer Anlagen, gemeinsames Ministerialblatt Ausgabe A, Nr. 32, vom 26.11.79 S. 668-683.

3. Compare NRC Regulatory Guide 1.97

4. Spiers, F.W., et al: A Guide to the Measurement of Environmental Gamma-Ray Dose Rate, BCRU 1981, (Report published by the national Physical Laboratory, Tedington, Middlesex TW 11 OLW, U.K.).

5. Portable or Installed X or Gamma Radiation Absorbed Dose Rate Meters for Measuring Environmental Dose Rate in Air, IEC-Dokument 45 B (Central Office) 52, Genf, März 1983

6. Rahmenempfehlung für die Fernüberwachung von Kernkraftwerken vom 11.9.80, BMI RS II 4-515 607/3

7. Anforderungen der PTB an ortsfeste Strahlenschutzmeßsysteme für die innerstaatliche Zulassung zur Eichung vom 15.11.1981, PTB-Mitteilung 91, 6/81, S. 454-458

8. Maushart, R., Kriterien zur Auswahl von Detektoren für Dosisleistungsmeßsysteme zur Umgebungsüberwachung kerntechnischer Anlagen, Atomenergie-Kerntechnik Vol. 43 (1983) No. 2 p. 91-94.

9. Beck, H.L.: Spectral Composition of the Gamma-Ray Exposure Rate due to Noble Gases Released during a Reactor Accident. Health Physics 43 (No. 3) (1982) 335-343

10. R. Maushart, J. Eppler, Dosisleistungsmessung zur Immissionsüberwachung in der Umgebung von Kernkraftwerken, Nuclex International Fair Conference, Session E Paper No. 5, Basel 1981

11. R. Maushart, Some Remarks Relating to Calibration of Environmental Doserate Measuring Systems, Radiation Protection Dosimetry, Vol. 3 No. 1 (1983).

12. Bøtter-Jensen, A Nordic Intercomparison for Background Radiation Monitoring Systems, Risø M 2266, April 1981.