Report 54992

Ludlum 44-9 Compensation Filter Design

1 INTRODUCTION

The aim of this project was to design removable energy compensation filters, to realise the quantities exposure and ambient dose equivalent, suitable for use with the Ludlum model 44-9 and prototype model 26 pancake GM probes. The 44-9 and prototype model 26 are portable pancake probe with a GM tube designed to detect alpha, beta, and gamma radiation. The target was to achieve a normalised energy response with a variation of < ±20% over the energy range 20 keV to 1.25 Mev (^{60}Co). In addition to the above, measurements were made of the variation of response with angle for each of the finalised filter designs. These measurements were performed at angles of up to ±75° to the normal irradiation geometry for ^{137}Cs and ^{241}Am. Linearity measurements were also performed using ^{137}Cs, in order to establish the count rate / dose rate characteristics of the detector. The results presented in this report are based on measurements performed using the model 44-9 probe. For the measurements detailed above, no significant variation in performance was noted between the model 44-9 and the prototype model 26 probe housings.

For the purpose of these tests, the probes were connected to a Ludlum model 2200 scaler / timer rate meter. All measurements were performed in the integrate mode, with counting times chosen to achieve the desired level of statistical uncertainty.

Traceability:	All the radiation quantities and sources used for the measurements performed in this report conform to the relevant ISO Standards. All the equipment associated with the measurements performed in this report have calibrations directly traceable to national standards via the National Physical Laboratory, PTB or UKAS Accredited calibration facilities
Uncertainties:	The uncertainties associated with the measurements performed in this report are expressed at the 95% confidence level. Where applicable, all uncertainties are summed in quadrature.

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Date:	09 June 2010

2 RELATIVE INTRINSIC ERROR

2.1 Ambient dose equivalent compensation filter

The instrument's relative intrinsic error was determined over a range of Ambient dose equivalent rate range using ^{137}Cs gamma radiation. Instrument indication represents integrated counts over exposure time. The response factor, defined as the ratio of the count rate to the true ambient dose equivalent rate, above background, is provided in Table 1.

Table 1. Relative intrinsic error

Ambient Dose Equivalent Rate	Exposure Time	Instrument Indication	Response Factor	Uncertainty
Background	600 seconds	1.88 cps	---	±10 %
1.611 µSv h^{-1}	600 seconds	10.1 cps	5.10	±10 %
6.186 µSv h^{-1}	300 seconds	33.4 cps	5.10	±10 %
16.81 µSv h^{-1}	120 seconds	85.4 cps	4.97	±10 %
53.30 µSv h^{-1}	120 seconds	269.7 cps	5.02	±10 %
178 µSv h^{-1}	60 seconds	874.9 cps	4.90	±10 %
570 µSv h^{-1}	60 seconds	2449 cps	4.26	±10 %

2.2 Exposure compensation filter

The instrument's relative intrinsic error was determined over a range of air kerma rates using ^{137}Cs gamma radiation. Instrument indication represents integrated counts over exposure time. The response factor, defined as the ratio of the count rate to the true air kerma rate, above background, is provided in Table 2.

Table 2. Relative intrinsic error

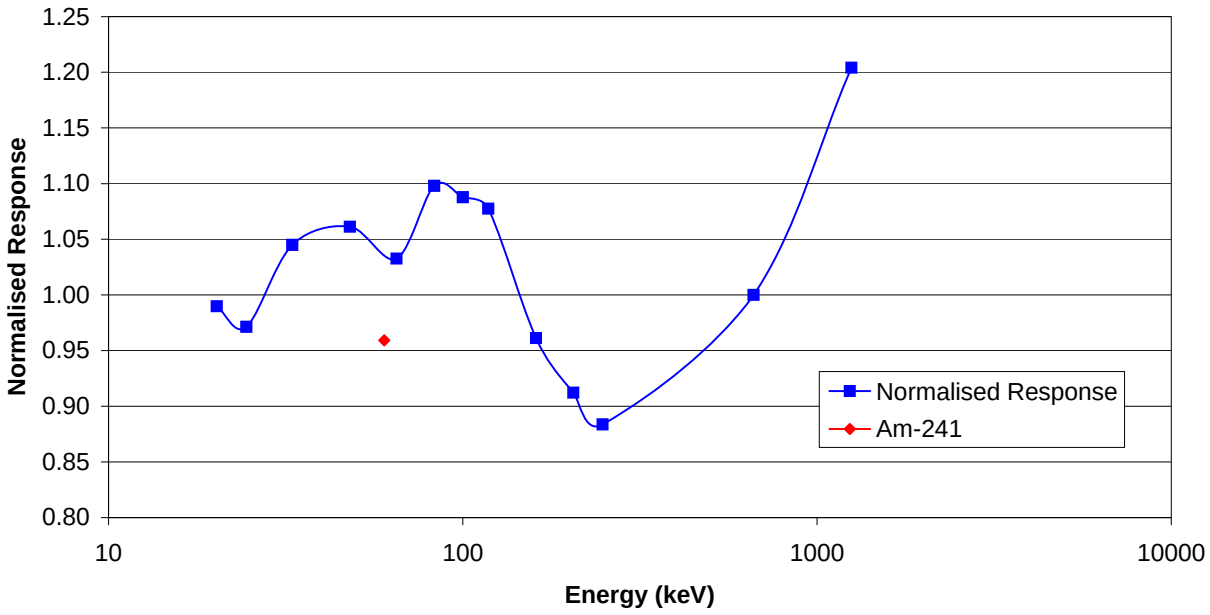
Air kerm Rate	Exposure Time	Instrument Indication	Response Factor	Uncertainty
Background	600 seconds	0.67 cps	---	±10 %
1.342 µGy h^{-1}	600 seconds	9.68 cps	6.71	±10 %
6.152 µGy h^{-1}	300 seconds	35.7 cps	6.80	±10 %
14.00 µGy h^{-1}	120 seconds	97.0 cps	6.88	±10 %
44.49 µGy h^{-1}	120 seconds	301.0 cps	6.75	±10 %
148.2 µGy h^{-1}	60 seconds	960.5 cps	6.44	±10 %
475.4 µGy h^{-1}	60 seconds	2684 cps	5.63	±10 %

3 VARIATION OF RESPONSE WITH PHOTON RADIATION ENERGY

3.1 Ambient dose equivalent compensation filter

The variation of response with photon energy was determined over the energy range 16.3 keV to 1.25 MeV. For energies 16.3 keV to 248 keV, x-radiation qualities were selected from the reference radiations recommended by the International Standards Organisations, i.e. the ISO Narrow series of filtered x-radiations. Gamma radiation emitted from ^{241}Am, ^{137}Cs and ^{60}Co sources provided the response to energies 60 keV, 662 keV and 1.25 MeV respectively. The response is defined as the ratio of the indicated count rate to the true ambient dose equivalent rate. The response, normalised to unity for ^{137}Cs (662 keV) at a value of 4.90 Counts s^{-1}/ µSv h^{-1}, is shown below in Figure 1, full results are provided in Appendix A.

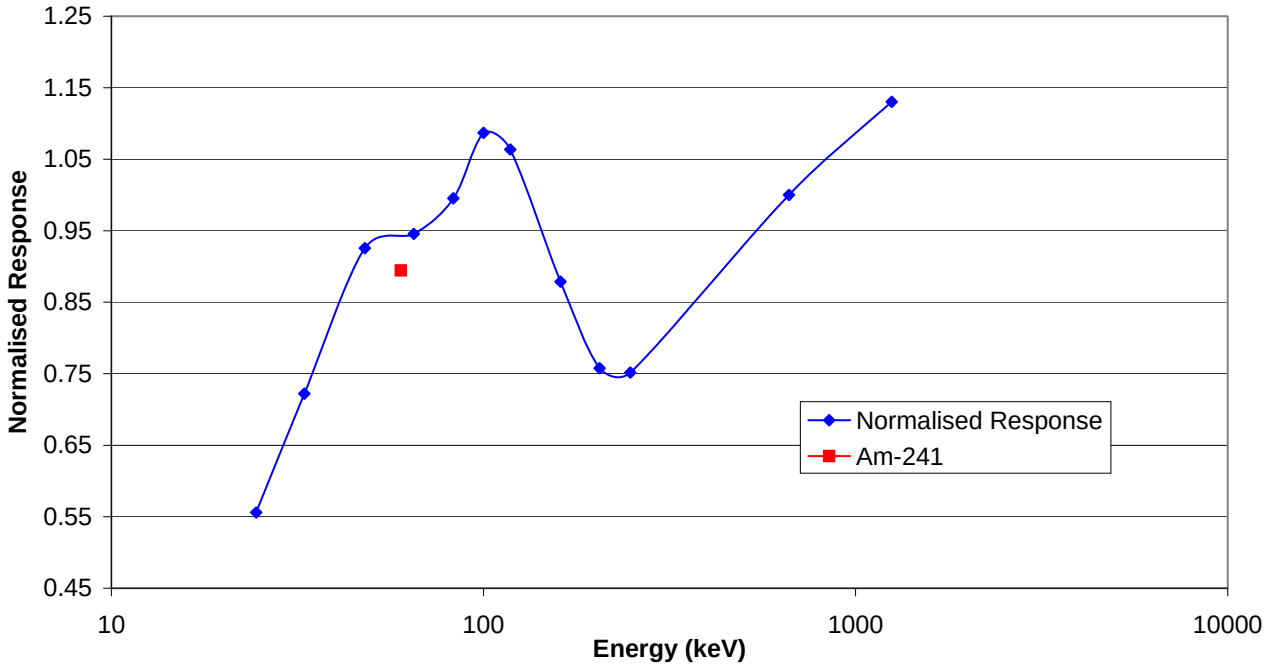
Figure 1. Variation of response with photon radiation energy



3.2 Exposure compensation filter

The variation of response with photon energy was determined over the energy range 16.3 keV to 1.25 MeV.. For energies 16.3 keV to 248 keV, x-radiation qualities were selected from the reference radiations recommended by the International Standards Organisations, i.e. the ISO Narrow series of filtered x-radiations. Gamma radiation emitted from ^{241}Am, ^{137}Cs and ^{60}Co sources provided the response to energies 60 keV, 662 keV and 1.25 MeV respectively. The response is defined as the ratio of the indicated count rate to the true air kerma dose rate. The response, normalised to unity for ^{137}Cs (662 keV) at a value of 6.44 Counts s^{-1}/ µGy h^{-1}, is shown below in Figure 2, full results are provided in Appendix B.

Figure 2. Variation of response with photon radiation energy

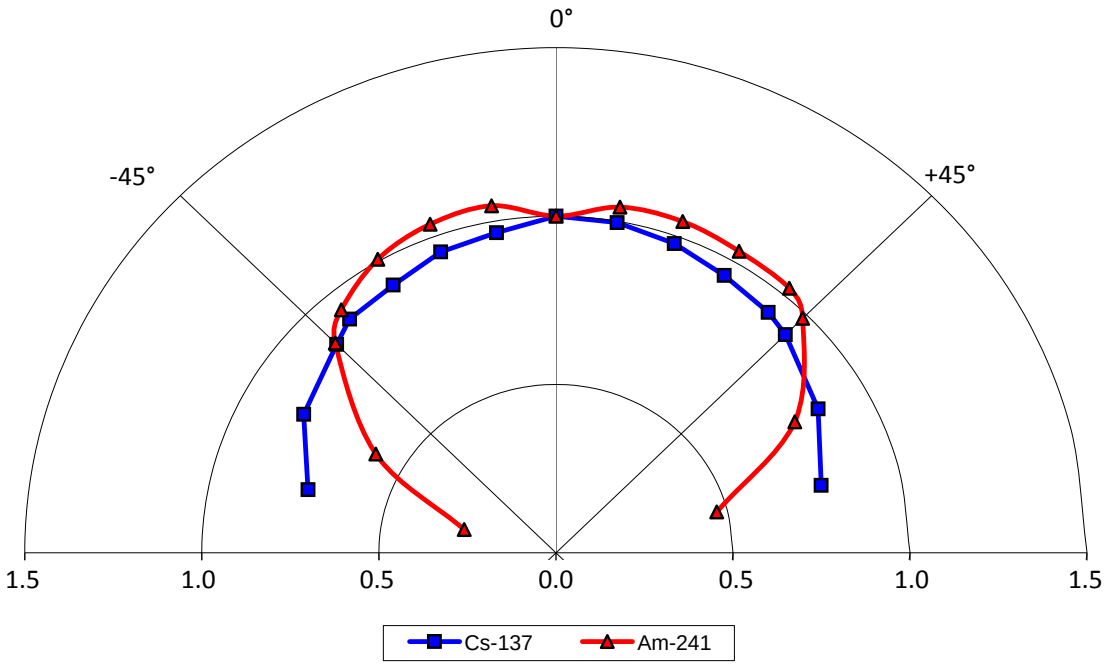


4 VARIATION IN RESPONSE WITH ANGLE OF INCIDENCE

4.1 Ambient dose equivalent compensation filter

Measurements were performed to determine the variation of response with angle of incidence using ^{137}Cs and ^{241}Am. The measurements were performed at angles of incidence up to $\pm 75^{o}$ in the vertical plane, + ve angles being towards the handle. The results have been normalised to 1.00 at 0^{o} i.e. the reference orientation with the radiation beam normal to the detector window, see Figure 3. Full results are provided in Appendix C.

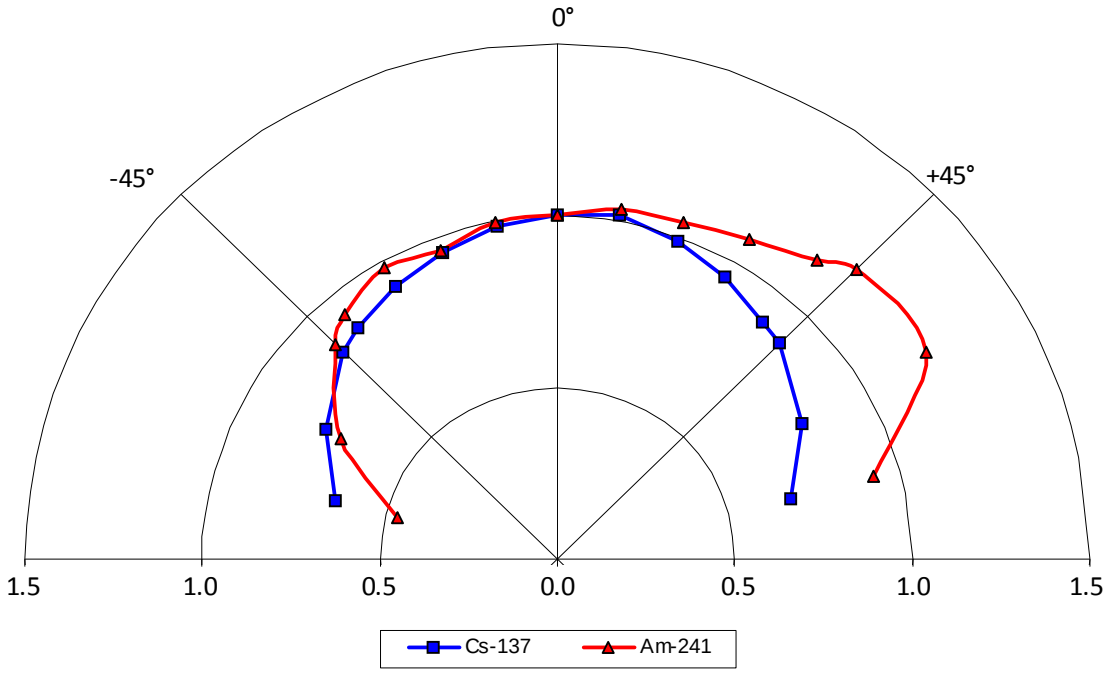
Figure 3. Variation of Response with Incident Angle



4.2 Exposure compensation filter

Measurements were performed to determine the variation of response with angle of incidence using ^{137}Cs and ^{241}Am. The measurements were performed at angles of incidence up to $\pm 75^{o}$ in the vertical plane, + ve angles being towards the handle. The results have been normalised to 1.00 at 0^{o} i.e. the reference orientation with the radiation beam normal to the detector window, see Figure 4. Full results are provided in Appendix D.

Figure 4. Variation of Response with Incident Angle



APPENDIX A

Variation of response with photon radiation energy

Ambient dose equivalent compensation filter

Radiation Quantity	Energy (keV)	Normalised Response	Uncertainty
^{60}Co γ-radiation	1250	1.20	±15 %
^{137}Cs γ-radiation	662	1.00	±15 %
ISO Narrow series x-radiation	248	0.88	±15 %
ISO Narrow series x-radiation	205	0.91	±15%
ISO Narrow series x-radiation	161	0.96	±15 %
ISO Narrow series x-radiation	118	1.08	±15 %
ISO Narrow series x-radiation	100	1.09	±15 %
ISO Narrow series x-radiation	83	1.10	±15 %
ISO Narrow series x-radiation	65	1.03	±15 %
^{241}Am γ-radiation	59.5	0.96	±15 %
ISO Narrow series x-radiation	48	1.06	±15 %
ISO Narrow series x-radiation	33	1.04	±15 %
ISO Narrow series x-radiation	24.5	0.97	±15 %
ISO Narrow series x-radiation	20.2	0.99	±15 %

APPENDIX B

Variation of response with photon radiation energy

Exposure compensation filter

Radiation Quantity	Energy (keV)	Normalised Response	Uncertainty
^{60}Co γ-radiation	1250	1.13	±15 %
^{137}Cs γ-radiation	662	1.00	±15 %
ISO Narrow series x-radiation	248	0.75	±15 %
ISO Narrow series x-radiation	205	0.76	±15 %
ISO Narrow series x-radiation	161	0.88	±15 %
ISO Narrow series x-radiation	118	1.06	±15 %
ISO Narrow series x-radiation	100	1.09	±15 %
ISO Narrow series x-radiation	83	1.00	±15 %
ISO Narrow series x-radiation	65	0.95	±15 %
^{241}Am γ-radiation	59.5	0.89	±15 %
ISO Narrow series x-radiation	48	0.93	±15 %
ISO Narrow series x-radiation	33	0.72	±15 %
ISO Narrow series x-radiation	24.5	0.56	±15 %

APPENDIX C

Variation of response with angle of incidence

Ambient dose equivalent compensated filter

Radiation Quality	Angle of Incidence	Normalised Response	Uncertainty
^{137}Cs (662 keV)	0°	1.00	±10 %
^{137}Cs (662 keV)	+10°	1.00	±10 %
^{137}Cs (662 keV)	-10°	0.97	±10%
^{137}Cs (662 keV)	+20°	0.98	±10 %
^{137}Cs (662 keV)	-20°	0.95	±10 %
^{137}Cs (662 keV)	+30°	0.95	±10 %
^{137}Cs (662 keV)	-30°	0.92	±10 %
^{137}Cs (662 keV)	+40°	0.93	±10 %
^{137}Cs (662 keV)	-40°	0.91	±10 %
^{137}Cs (662 keV)	+45°	0.92	±10 %
^{137}Cs (662 keV)	-45°	0.87	±10 %
^{137}Cs (662 keV)	+60°	0.86	±10 %
^{137}Cs (662 keV)	-60°	0.82	±10 %
^{137}Cs (662 keV)	+75°	0.78	±10 %
^{137}Cs (662 keV)	-75°	0.72	±10 %
^{241}Am (59.5 keV)	0°	1.00	±10 %
^{241}Am (59.5 keV)	+10°	1.04	±10 %
^{241}Am (59.5 keV)	-10°	1.05	±10 %
^{241}Am (59.5 keV)	+20°	1.05	±10 %
^{241}Am (59.5 keV)	-20°	1.04	±10 %
^{241}Am (59.5 keV)	+30°	1.03	±10 %
^{241}Am (59.5 keV)	-30°	1.01	±10 %
^{241}Am (59.5 keV)	+40°	1.03	±10 %
^{241}Am (59.5 keV)	-40°	0.94	±10 %
^{241}Am (59.5 keV)	+45°	0.99	±10 %
^{241}Am (59.5 keV)	-45°	0.88	±10 %
^{241}Am (59.5 keV)	+60°	0.78	±10 %
^{241}Am (59.5 keV)	-60°	0.59	±10 %
^{241}Am (59.5 keV)	+75°	0.47	±10 %
^{241}Am (59.5 keV)	-75°	0.27	±10 %

APPENDIX D

Variation of response with angle of incidence

Exposure compensated filter

Radiation Quality	Angle of Incidence	Normalised Response	Uncertainty
^{137}Cs (662 keV)	0°	1.00	±10 %
^{137}Cs (662 keV)	+10°	1.02	±10 %
^{137}Cs (662 keV)	-10°	0.98	±10 %
^{137}Cs (662 keV)	+20°	0.99	±10 %
^{137}Cs (662 keV)	-20°	0.95	±10 %
^{137}Cs (662 keV)	+30°	0.95	±10 %
^{137}Cs (662 keV)	-30°	0.92	±10 %
^{137}Cs (662 keV)	+40°	0.90	±10 %
^{137}Cs (662 keV)	-40°	0.88	±10 %
^{137}Cs (662 keV)	+45°	0.89	±10 %
^{137}Cs (662 keV)	-45°	0.85	±10 %
^{137}Cs (662 keV)	+60°	0.79	±10 %
^{137}Cs (662 keV)	-60°	0.75	±10 %
^{137}Cs (662 keV)	+75°	0.68	±10 %
^{137}Cs (662 keV)	-75°	0.65	±10 %
^{241}Am (59.5 keV)	0°	1.00	±10 %
^{241}Am (59.5 keV)	+10°	1.03	±10 %
^{241}Am (59.5 keV)	-10°	1.00	±10 %
^{241}Am (59.5 keV)	+20°	1.04	±10 %
^{241}Am (59.5 keV)	-20°	0.96	±10 %
^{241}Am (59.5 keV)	+30°	1.08	±10 %
^{241}Am (59.5 keV)	-30°	0.98	±10 %
^{241}Am (59.5 keV)	+40°	1.14	±10 %
^{241}Am (59.5 keV)	-40°	0.93	±10 %
^{241}Am (59.5 keV)	+45°	1.19	±10 %
^{241}Am (59.5 keV)	-45°	0.88	±10 %
^{241}Am (59.5 keV)	+60°	1.20	±10 %
^{241}Am (59.5 keV)	-60°	0.70	±10 %
^{241}Am (59.5 keV)	+75°	0.92	±10 %
^{241}Am (59.5 keV)	-75°	0.47	±10 %