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G01T 3/00

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G6P P5B3 P5B4 P5D

(56) Documents Cited

EP 0403105 A	**US 5532481 A**	**US 4814623 A**
US 4251724 A	**US 4197463 A**	

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UK CL (Edition Q) **G6P**
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EPOQUE: WPI, EPODOC, PAJ

(54) Abstract Title
Apparatus for measuring neutron radiation

(57) A neutron detector comprising a beta detector 104 and an adjacent layer of activatable material 200 which generates beta particle in response to incident neutrons. Additionally a neutron moderator layer 208, a shield layer 206, an absorption layer 204 and a light shield 202 may be provided. More than one such neutron detector may be provided so that fast and slow neutrons can be detected. The neutron detector may be provided in addition to gamma and X-ray detectors in a personal dosemeter.

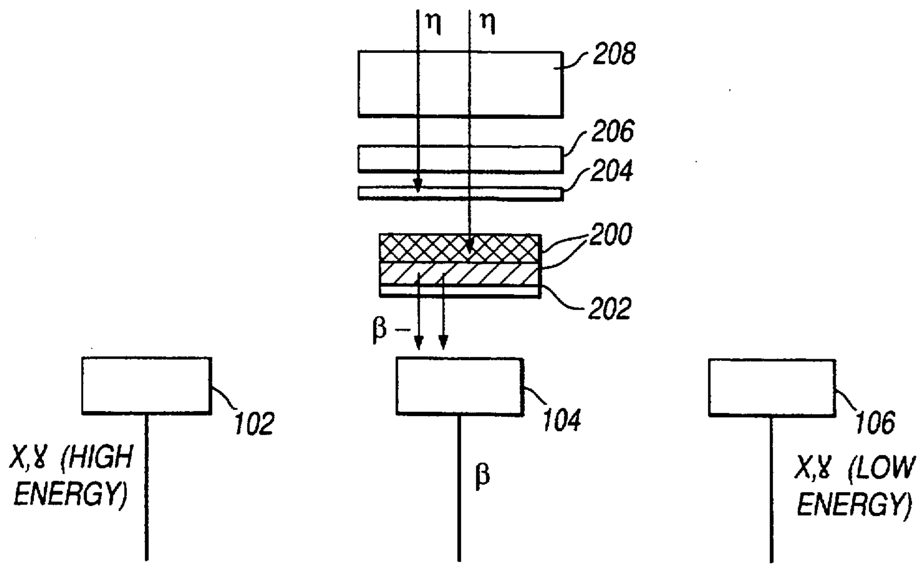

Fig.2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

GB 2 352 081 A

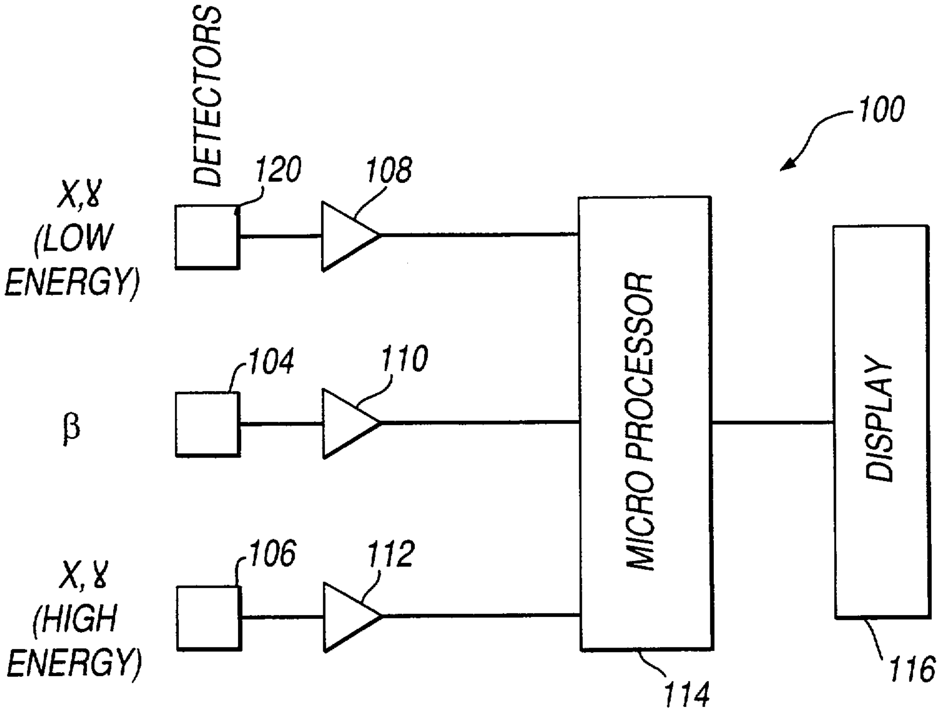
DETECTORS
100
X,γ (LOW ENERGY)
120
108
β
104
110
X,γ (HIGH ENERGY)
106
112
MICRO PROCESSOR
114
DISPLAY
116

Fig.1

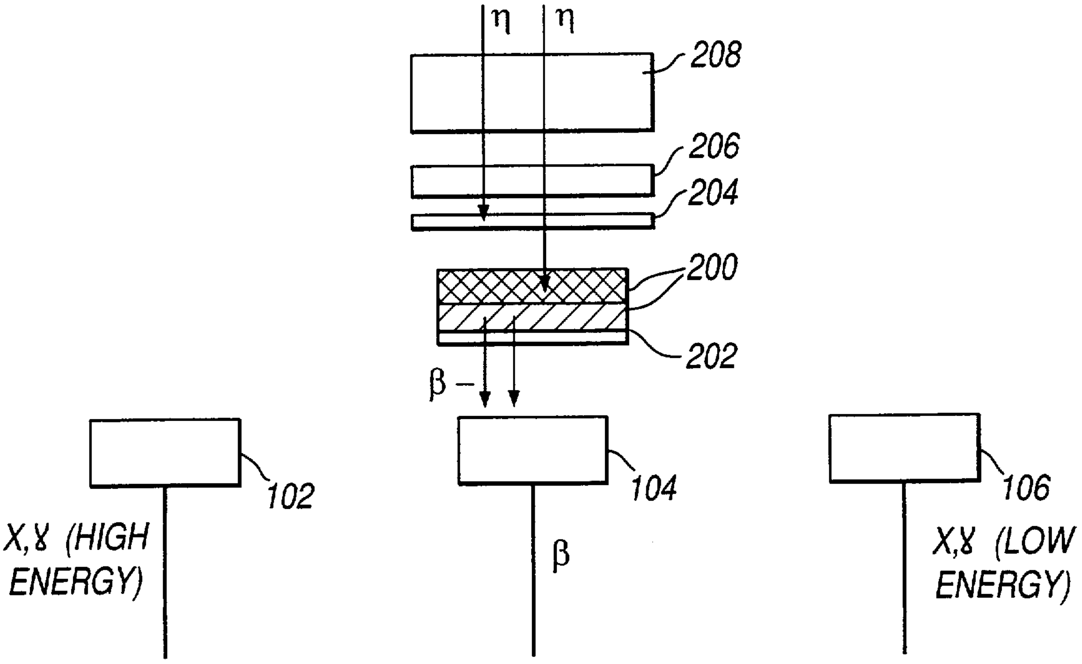
η
η
208
206
204
200
202
β −
102
X,γ (HIGH ENERGY)
104
β
106
X,γ (LOW ENERGY)

Fig.2

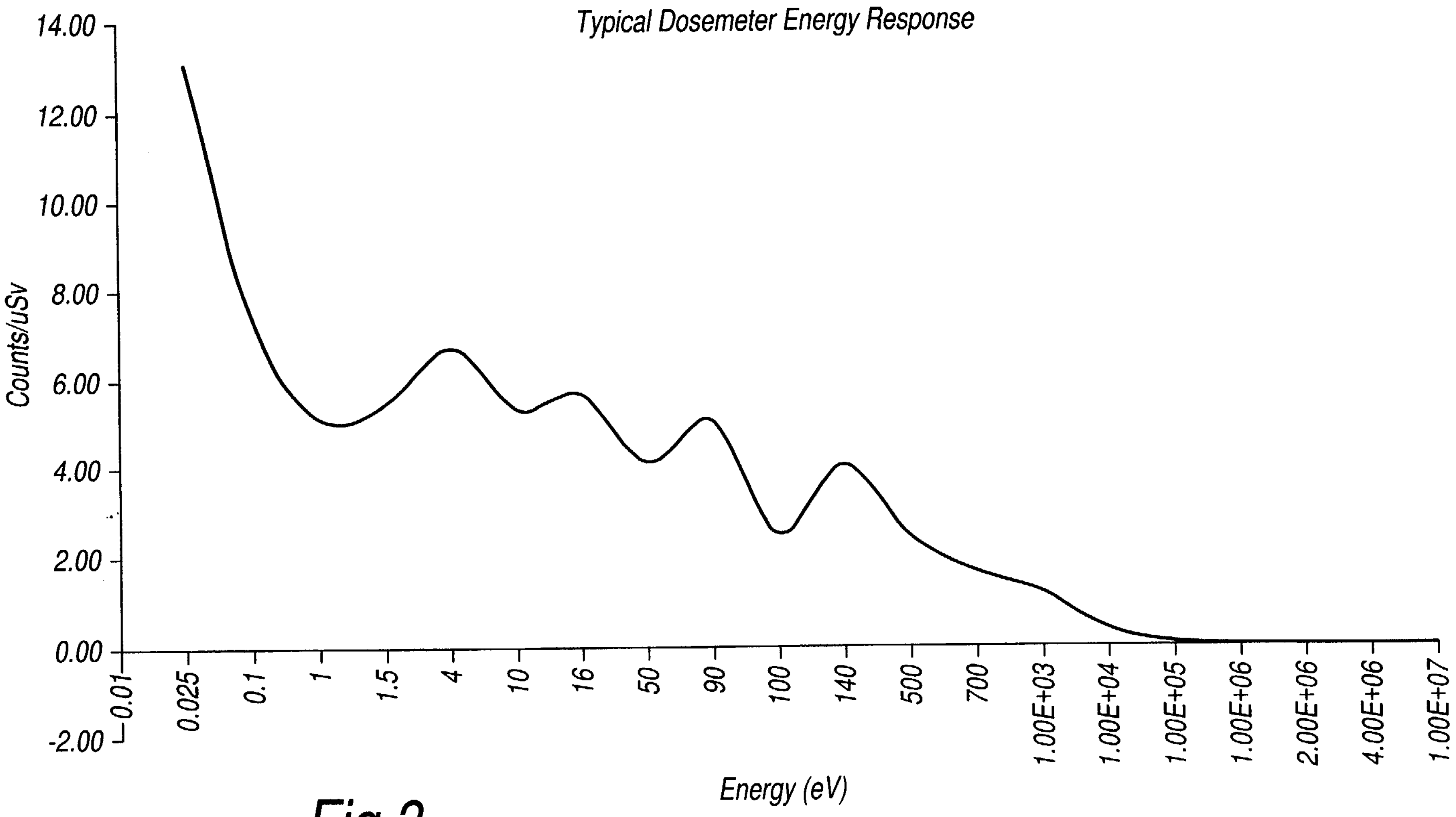
Typical Dosemeter Energy Response
Counts/uSv
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0.01
0.025
0.1
1
1.5
4
10
16
50
90
100
140
500
700
1.00E+03
1.00E+04
1.00E+05
1.00E+06
2.00E+06
4.00E+06
1.00E+07
Energy (eV)

Fig.3

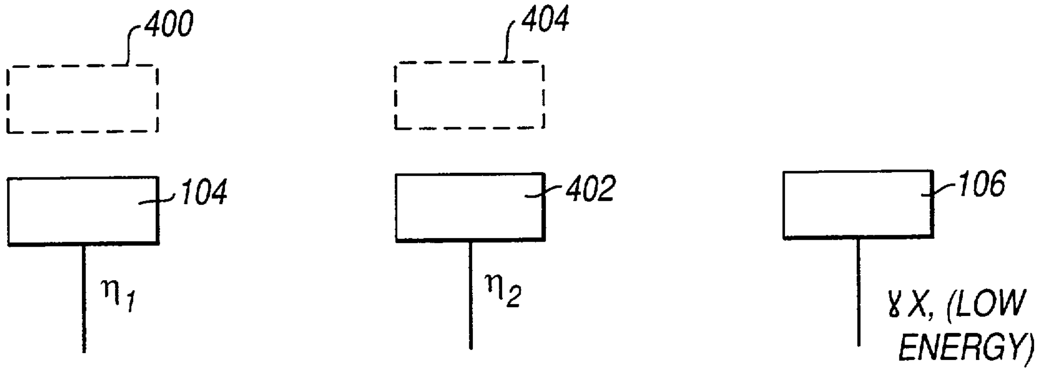

Fig.4

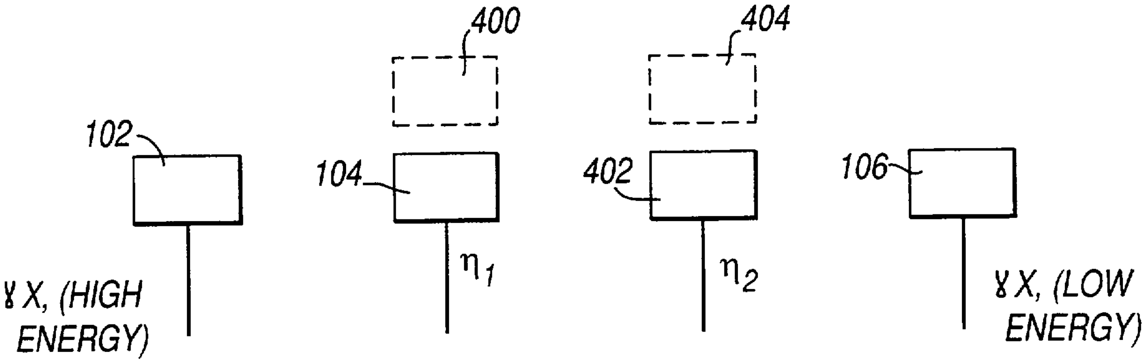

Fig.5

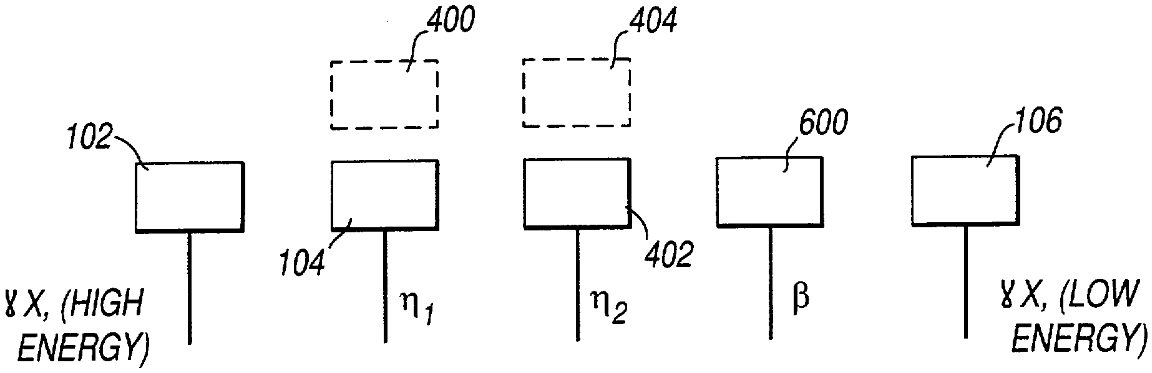

Fig.6

APPARATUS FOR MEASURING NEUTRON RADIATION

The present invention relates to an apparatus for measuring neutron radiation. More particularly, the invention relates to personal radiation dosemeters of the type worn by individuals likely to be exposed to a radiation field.

During operation of nuclear reactors, and other nuclear facilities, individuals may need to work in areas where there may be significant prevailing neutron radiation dose rates. It is therefore desirable to have a means of estimating the neutron dose received in real time by individuals exposed to neutron radiation.

In the field of passive neutron dosimetry, there are several dosemeter constructions known, including: film dosemeters, thermoluminescent dosemeters, dosemeters which exploit neutron interactions with certain plastics, and neutron bubble counters. Active neutron dosemeters are also commercially available in a variety of forms, including; quartz fibre electroscopes, and active electronic dosemeters using direct interaction of neutrons with a solid-state detector. Other types of dosemeters are also known, but these dosemeters suffer from the disadvantages of being insensitive to neutron radiation, incapable of providing good discrimination between neutron and gamma radiation, or are designed to react to a sudden, large, dose of radiation. An example of the latter type of dosemeter is a criticality locket, which is designed to react to large doses of neutron radiation, typically tens of milliSievert (mSv) or more, but criticality lockets are passive dosemeters and cannot be read in real-time.

Figure 1 is a schematic diagram of one known dosemeter manufactured by Siemens Environmental Systems Limited under the trade mark Electronic Personal

Dosemeter (EPD®) Mk2. The dosemeter 100 comprises a first detector 102, a second detector 104, and a third detector 106 coupled to a first amplifier 108, a second amplifier 110 and a third amplifier 112, respectively. The first amplifier 108, the second amplifier 110, and the third amplifier 112 are each coupled to a microprocessor 114 which is coupled to a display 116.

The first detector 102 and the first amplifier 108 constitute a first detection channel. Similarly the second detector 104 and the second amplifier 110, and the third detector 106 and the third amplifier 112 constitute a second detection channel and a third detection channel, respectively. The first detection channel is sensitive to high-energy photon radiation, i.e. the x-ray and gamma (γ) radiation alone, the third detection channel being primarily sensitive to low-energy photon radiation. The second detection channel is sensitive to both photon radiation and beta (β) particles. The microprocessor 114 carries out signal processing techniques in order to discriminate between β-particles and higher- and lower-energy photon radiation, and determines a wearer's dose in terms of the ICRU (International Commission on Radiation Units and Measurements) dose quantities $H_p(10)$ and $H_p(0.07)$. The dosemeter 100 will not be described in further detail, because its structure is known and is the subject of European patent application number 90305816.2.

Another problem encountered with personal dosemeters worn by an individual on the front of the individual's trunk is that the response of the dosemeter is affected by the body of the individual wearing the dosemeter and the orientation of the individual with respect to the neutron radiation source. Specifically, the human body comprises a large percentage of water or water-equivalent material which has very significant moderating and reflective properties with regard to neutrons. Therefore, the response of a neutron dosemeter due to neutrons incident upon the front of an individual, where the dosemeter is located, is affected by a well-known "albedo" effect. The albedo effect is the moderation and reflection of neutrons by an individual's body, a proportion of these neutrons being detectable by the dosemeter.

Additionally, depending upon the neutron source, neutron radiation can be accompanied by high levels of γ radiation. Alternatively, at other times or locations, the prevailing neutron radiation level can be much higher than the γ radiation level. It is therefore another object of the present invention to provide a neutron dosemeter which can discriminate neutron radiation from interfering γ radiation.

According to the present invention there is provided an apparatus for measuring neutron radiation, comprising a detector coupled to a processor, the detector being arranged to detect β radiation particles, wherein a layer of an activatable material is provided adjacent the detector, the layer of the activatable material being capable of radiating β-particles in response to neutron particles incident upon a first surface of the activatable material.

The apparatus may further comprise a window layer located between a second surface of the layer of the activatable material and the detector, the window layer being capable of inhibiting the passage of radiation therethrough, in particular, electromagnetic radiation in the optical range of the electromagnetic spectrum and longer wavelengths, for example, microwave radiation, capable of interfering with the apparatus' electronics.

Preferably, the apparatus further comprises a neutron absorption layer adjacent the first surface of the layer of the activated material.

Preferably, the apparatus further comprises a shield layer disposed adjacent the absorption layer.

Preferably, the apparatus further comprises a layer of moderating material disposed adjacent the shield layer.

Advantageously, the apparatus further comprises a second detector arranged to detect β radiation particles, wherein a respective layer of an activatable material is provided adjacent the second detector, the second layer of the activatable material being capable of radiating β-particles in response to neutron particles incident upon a first surface of the respective activatable material, the respective activatable material being of a different type and/or thickness to the activatable material adjacent the first detector.

Preferably, the apparatus further comprises a third detector arranged to detect photon-based radiation.

In a preferred embodiment of the invention, there is provided a personal radiation dosemeter comprising the apparatus for measuring neutron radiation as described above.

It is thus possible to provide a dosemeter having a low detection threshold which can discriminate between photon radiation and neutron radiation. The present invention also allows measurement of doses and dose rates in real-time, and consequently facilitates the provision of alarms in real-time. Due to the fact that the activity of the activatable material does not decay immediately, it is possible for high neutron levels delivered at very high rates to be measured. Additionally, the dosemeter according of the present invention possesses low self-noise, i.e. the dosemeter's signal processing electronics do not introduce significant noise into signals generated by the detector(s).

At least one embodiment of the invention will now be described, by way of example, with reference to the accompanying drawing, in which:

Figure 2 is a schematic diagram of an adaptation of the dosemeter of Figure 1;

Figure 3 is a graph illustrating the dosemeter response to neutron energy;

Figure 4 is a schematic diagram of a dosemeter constituting a third embodiment of the invention;

Figure 5 is a schematic diagram of a dosemeter constituting a fourth embodiment of the invention, and

Figure 6 is a schematic diagram of a dosemeter constituting a fifth embodiment of the invention.

Throughout the description, identical reference numerals will be used in the drawings to identify like parts.

Referring to Figure 1, in a first embodiment of the invention, each of the first detector 102, the second detector 104 and the third detector 106 have respective windows/filters (not shown in Figure 1) having specific energy responses to incident ionising radiation. Consequently, the first detector 102 responds to higher-energy x-ray and γ radiation, the third detector 106 only responds to lower-energy x-ray and γ radiation, whilst the second detector 104 responds to x-ray and γ radiation as well as β-particles.

By means of discriminators, the sensitivity of each of the first detector 102, the second detector 104, and the third detector 106 is adjusted. Signal processing techniques are used by the microprocessor 114 to count pulses generated separately in respect of β-particles, low energy photons and high-energy photons. The pulses are processed by the microprocessor 114 according to an algorithm, which will be described later in more detail, to obtain the values of the personal dose equivalents $H_p(10)$ and $H_p(0.07)$.

A window 202 (referred to above in relation to Figure 1) formed from Aluminium and/or polyimide, such as KAPTON® manufactured by DuPont®, is located adjacent the detecting surface of the second detector 104 and allows β particles to pass therethrough in preference to light in the optical range of the electromagnetic spectrum. The window 202 forms part of the case construction of the dosemeter and also forms part of the screening for the detector circuits of the dosemeter. The screening is provided to prevent possible interference caused by non-ionising electromagnetic radiation, such as microwaves.

The above described known dosemeter 100 is adapted by providing a thin layer 200 of an activatable material adjacent the window 202. The activatable material is defined as including any material which is capable of producing β-particles in response to neutrons being incident upon the material, for example, a metal foil such as gold, indium or silver foil. It should be appreciated that the invention is not limited to these particular types of foil and other materials falling within the above definition of activatable materials are contemplated. It is preferable to select materials where the products of neutron activation have short half-lives for radioactive decay, in order to optimise the response time of the adapted dosemeter. Typically, the activatable layer 200 is about 0.01 to 0.2 mm thick.

As shown in Figure 2, more than one layer of respectively different types of the activatable material can be used in order to vary the generation of β-particles in response to incident neutrons of different energies. The thickness of the layer (or in the case of more than one layer, each layer) of activatable material can be varied in order to influence the number of β-particles produced in response to a given neutron flux, i.e. in order to vary the response of the adapted dosemeter. The response to neutron radiation of the dosemeter 100 after the above-described adaptation is shown in Figure 3.

The β-particles generated by the layer of activatable material 200 are emitted over 4π-geometry, a proportion of which are detected by the second detector 104. Clearly, it can be seen that the number of counts recorded by the second detector 104 is proportional to the neutron flux to which the adapted dosemeter, and consequently the individual wearing the adapted dosemeter, is exposed.

In a second embodiment of the invention, low energy neutrons incident from the front of the individual's trunk can be prevented from reaching the second detector 104 by using an absorption layer 204 of a material with a high neutron absorption cross-section, for example, cadmium. The absorption layer 204 can be placed adjacent the layer of activatable material 200 and typically is about 1mm thick. It is thus possible to reduce the sensitivity of the second detector 104 to thermal neutrons from the front of the individual's trunk and hence to modify the response of the adapted dosemeter to neutrons of various energies.

A shield layer 206 can be provided adjacent the absorption layer 204 in order to shield the second detector from external, interfering, β-particles.

Optionally, a moderating layer 208 is provided adjacent the shield layer 206 to decelerate faster neutrons, thereby making the faster neutrons more detectable. Typically, the moderating layer 208 is formed from a plastic material, for example, polyethylene, and is about 10 to 20 mm thick.

In operation, the microprocessor 114 executes a first algorithm in order to calculate the dose of neutron radiation in terms of the neutron contribution to the personal dose equivalent quantity $H_p(10)$. The first algorithm is based upon the following equations:

$$H_p(10)(\text{photon}) = K_1(HG) + K_2(SG) \quad (1)$$

$$H_p(10)(\text{neutron}) = K_3(HG) + K_4(SG) + K_5FB - K_6BC \quad (2)$$

Where: $K_1, K_2, K_3, \ldots, K_6$ are calibration constants.

HG is the number of counts due to high-energy photons detected by the first detector 102,

SG is the number of counts due to low-energy photons detected by the third detector 106,

FB is the number of counts due to beta-radiation detected by the second detector 104, and

BC is the beta compensating count, i.e. the number of counts due to photon radiation detected by the third detector 106 corresponding to the number of counts attributable to X and γ radiation detected by the second detector 104. The beta compensating count is obtained by introducing a discriminator facility so as to provide a second pulse train corresponding to the signal generated by the third detector 106.

Constants K_3 and K_4 are arranged to be equal to zero, whilst constants K_5 and K_6 are adjusted to take account of the layers of material adjacent the detecting side of the second detector 104, for example, activatable layers and/or shields.

A second algorithm is executed by the microprocessor 114 using signals received from the first and third detectors 102, 106 in order to determine the contribution to the personal dose equivalent from photon-based radiation.

The microprocessor 114 drives the display 116 which is, in this example, a liquid crystal display (LCD). Software for driving the display is known to, or can be written by, a person skilled in the art. However, such software does not relate directly to the present invention and so will not be described further.

The display 116 is capable of displaying the contributions from neutron and photon-based radiation to personal dose equivalents, separately, as well as displaying the total derived personal dose equivalent; this is the sum of the contributions from neutron and photon-based radiation.

The adapted dosemeter can be calibrated using a suitable human trunk phantom exposed to neutron radiation reflecting the typical conditions to which an individual would be exposed. The human trunk phantom is a block of tissue-equivalent material, for example perspex or a tank of water, approximately the size of a human torso used to simulate the presence of the human trunk. The measurement of the neutron radiation by the adapted dosemeter is compared to a recognised expected value according to international standards for calibration of dosemeters for use in neutron fields.

In situations where the neutron energy spectrum, i.e. the relative abundance of neutrons of different energies, differs significantly from the energy spectrum of the field in which the adapted dosemeter was calibrated, the calibration constant K_5 (which can be considered as a product of two or more parameters) can be adjusted to regulate the response of the adapted dosemeter, i.e. in terms of the ratio of measured dose : true dose. Where the energy spectra are well known for different working areas of a nuclear establishment, the adapted dosemeter can be programmed with area-specific calibration constants using a computerised dosimetry system available from Siemens Environmental Systems Limited.

The adapted dosemeter is capable of determining thermal neutron dose rates of less than 10μSv/h in a γ radiation field of approximately 20μSv/h. Such sensitivity is possible due to the very low intrinsic noise of the adapted dosemeter and the β/γ discrimination, i.e. the adapted dosemeter is capable of measuring β and γ radiation separately. Consequently, since neutrons are converted into β-particles, by the layer of activatable material 200, the dosemeter 100 has a good n/γ discrimination.

Referring to Figure 4, in a second embodiment of the invention, the layers 200, 202, 204, 206 are generally designated as a set of layers 400. The first detector 102 is replaced by an additional beta detector 402. A second set of layers 404 are disposed adjacent the additional beta detector 402. The second set of layers 404 have a similar structure to the set layers 400. However, the layer(s) of activatable material(s) 200, the absorption layer 204, shield layer 206 and moderating layer 208 in the second set of layers 404 differ from the corresponding layers, for example material(s) used, in the set of layers 400. The material(s) used in the second set of layers 404 are selected so that the additional beta detector 402 has a higher response than the set of layers 400 to faster neutrons (in terms of β counts per unit neutron flux). The dosemeter arrangement of this embodiment has an improved neutron energy response, the algorithm for detection of neutrons being given by the following equation:

$$H_p(10)\ (\text{neutron}) = K_7\,(402) - K_8(BC) + K_9(FB) - K_{10}(BC)$$

$$= K_7\,(402) + K_9(FB) - K_{11}(BC) \qquad (3)$$

where $K_7,\ldots,K_{11}$ are calibration constants and $K_7(402)$ is the product of the calibration constant K_7 with a signal from the additional beta detector 402.

In a fourth embodiment of the invention illustrated in Figure 5, instead of replacing the first detector 102 with the additional beta detector 402, the first detector 102 is retained and the additional beta detector 402 supplements the first, second and third detectors 102, 104, 106 described above in accordance with the first embodiment of the invention. The adapted dosemeter of this embodiment is capable of accurately providing $H_p(10)$ (photon) measurements whilst still providing the improved neutron energy response of the dosemeter arrangement described above in relation to the third embodiment.

In a fifth embodiment of the invention, the adapted dosemeter of the third embodiment described above is supplemented by an unmodified beta detector 600 for detecting the presence of beta particles. The dosemeter of this embodiment is thus capable of measuring the dose quantity $H_p(0.07)$, in addition to the $H_p(10)$ photon measurement and neutron response described above in relation to the fourth embodiment.

It should be appreciated the present invention is not limited to the above described embodiments and that other, alternative, embodiments falling within the scope of the appended claims are conceivable.

CLAIMS

1. Apparatus for measuring neutron radiation, comprising a detector coupled to a processor, the detector being arranged to detect β radiation particles, wherein a layer of an activatable material is provided adjacent the detector, the layer of the activatable material being capable of radiating β-particles in response to neutron particles incident upon a first surface of the activatable material.

2. An apparatus as claimed in Claim 1, further comprising a window layer located between a second surface of the layer of the activatable material and the detector, the window layer being capable of inhibiting the passage of electromagnetic radiation therethrough the electromagnetic radiation being in the optical range of the electromagnetic spectrum.

3. An apparatus as claimed in Claim 1 or Claim 2, further comprising a neutron absorption layer adjacent the first surface of the layer of the activated material.

4. An apparatus as claimed in Claim 3, further comprising a shield layer disposed adjacent the absorption layer.

5. An apparatus as claimed in Claim 4, further comprising a layer of moderating material disposed adjacent the shield layer.

6. An apparatus as claimed in Claim 1, further comprising a second detector arranged to detect β radiation particles, wherein a respective layer of an activatable material is provided adjacent the second detector, the second layer of the activatable material being capable of radiating β-particles in response to neutron particles incident upon a first surface of the respective activatable material, the respective

activatable material being of a different type to the activatable material adjacent the first detector.

7. An apparatus as claimed in Claim 1, further comprising a third detector arranged to detect photon based radiation.

8. A personal radiation dosemeter comprising the apparatus for measuring neutron radiation as claimed in any one of the preceding claims.

9. An apparatus for measuring neutron radiation substantially as hereinbefore described with reference to the accompanying drawings.

Amendments to the claims have been filed as follows

1. A personal dosemeter for measuring neutron radiation, comprising a first detector coupled to a processor, the first detector being arranged to detect β radiation particles, and a second detector arranged to detect photon based radiation, wherein a layer of an activatable material is provided adjacent the first detector, the layer of the activatable material being capable of radiating β-particles as a result of a decay process in the activatable material caused by an incidence of neutron upon a first surface of the activatable material.

2. An apparatus as claimed in Claim 1, further comprising a window layer located between a second surface of the layer of the activatable material and the first detector, the window layer being capable of inhibiting the passage of electromagnetic radiation therethrough the electromagnetic radiation being in the optical range of the electromagnetic spectrum.

3. An apparatus as claimed in Claim 1 or Claim 2, further comprising a neutron absorption layer adjacent the first surface of the layer of the activated material.

4. An apparatus as claimed in Claim 3, further comprising a shield layer disposed adjacent the absorption layer.

5. An apparatus as claimed in Claim 4, further comprising a layer of moderating material disposed adjacent the shield layer.

6. An apparatus as claimed in Claim 1, further comprising a further detector arranged to detect β radiation particles, wherein a respective layer of an activatable material is provided adjacent the further detector, the respective layer of the activatable material being capable of radiating β-particles in response to neutron

particles incident upon a first surface of the respective activatable material, the respective activatable material being of a different type to the activatable material adjacent the first detector.

7. An apparatus as claimed in Claim 1, further comprising a third detector arranged to detect photon based radiation.

8. An apparatus for measuring neutron radiation substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

INVESTOR IN PEOPLE

Application No: GB 9916700.9
Claims searched: 1-9
Examiner: Emma Rendle
Date of search: 24 September 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G6P

Int Cl (Ed.6): G01T 1/16, 1/28, 3/00, 3/02, 3/08; G01V 5/10

Other: EPOQUE: WPI, EPODOC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	US 5 532 481	(WESTERN ATLAS) see whole document, noting first and second neutron detectors.	6
X, Y	US 4 814 623	(UNIVERSITY OF NEW MEXICO) see whole document, especially figure 3.	X:1, 2, 3 Y:6
Y	US 4 251 724	(IRT CORPORATION) se whole document, noting plural neutron cetectors	6
X, Y	US 4 197 463	(WESTINGHOUSE) see whole document.	X:1 Y: 6
A	EP 0 403 105	(NATIONAL RADIOLOGICAL PROTECTION) see whole document.	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		