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THE ACTIVE PERSONNEL DOSIMETER — APFEL ENTERPRISES SUPERHEATED DROP DETECTOR*

N. E. Ipe, R. J. Donahue, and D. D. Busick

Stanford Linear Accelerator Center
Stanford University, Stanford, CA 94309, USA

Abstract — The Active Personnel Dosimeter (APD) provides a digital readout of events caused by neutrons interacting with superheated liquid droplets. The droplets are suspended in a gel held in a replaceable cartridge. Upon neutron interaction, the superheated droplet vaporises, forming a bubble. The sound produced in this process is recorded by transducers that sense the accompanying pressure pulse. The APD electronically discriminates against spurious noise and vibration. Studies with the production prototype APDs indicate that the detector response is linear up to about 0.40 mSv, with large variations sometimes from predicted values and between cartridges at higher dose equivalents. The response to standard neutron sources (bare ^{252}Cf, PuBe, PuB, PuF, PuLi) is reported and compared with the expected response. Unirradiated cartridges self-nucleate when heated to temperatures of 46°C. The APD is insensitive to low-energy photons but responds to high-energy photons and electrons.

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INTRODUCTION

The APD available for neutron dosimetry from Apfel Enterprises° is an electronic instrument that provides a digital readout of events caused by neutrons interacting with droplets of superheated liquid.[1] The droplets are suspended in an immiscible, inert, impurity-free gel which is held in a replaceable cartridge that fits in the instrument. Upon neutron interaction, the superheated droplet vaporises, forming a bubble which slowly rises out of the gel. The sound produced by the vaporisation of the droplet is recorded by transducers that sense the accompanying pressure pulse. Each event results in an increment in the digital display and an audible "beep." The APD is battery powered and electronically discriminates against spurious noise and vibration.

According to the manufacturer, the energy response of the APD follows the ICRP 21-dose equivalent response within 40% for neutron energies above 100 KeV and within a factor of 10 for energies below 100 KeV. The detector under-responds in the thermal region. The APD has a high sensitivity, and a minimum detectable limit of 1 μSv. It is omnidirectional and insensitive to photons. The sensitivity of the detector, however, increases as the temperature of the detector increases.

In this paper, the results of studies performed with the APDs purchased as part of a production preview program (i.e., a program in which the experimenter reports the results to the manufacturer so that the manufacturer can improve the technology) are reported. Characteristics investigated are: effect of temperature; linearity and reproducibility; response to standard neutron sources (bare ^{252}Cf, PuBe, PuB, PuLi and PuF); effect of storage; and effect of photon and electron irradiation.

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° Apfel Enterprises, Inc., 25 Science Park, New Haven, CT 06511, USA.

PRINCIPLE OF OPERATION

The basic principle of operation of the superheated drop detector (SDD) is that boiling in a superheated liquid can be initiated by the presence of charged particles formed by radiation interacting with the detector.[2,3]

A liquid can be raised to a temperature above its boiling point without boiling actually occurring. This state of the liquid, known as the superheated state, is unstable; a slight disturbance or introduction of any impurities will cause the liquid to boil. The normal boiling point of a liquid is the temperature at which its saturation vapor pressure is equal to the external pressure. An increase in the external pressure results in an elevation of the boiling point and vice versa. When the SDD is sensitised (i.e., when the external pressure has been redu d), the droplets are in a superheated state.

Neutron irradiation results in the formation of secondary charged particles which deposit energy along their path, thus initiating vapor bubble formation. The vapor nucleation will depend on the energy deposited which, in turn, is dependent on the liquid and the degree of superheat. The more superheated a liquid is, the less energy it will require to trigger bubble formation. The nucleation step requires that a vapor bubble of a minimum size be formed. Bubbles smaller than this critical size are unstable and tend to collapse. Bubbles greater than this critical size will grow to a visible size by the evaporation of the superheated liquid until the whole droplet is consumed. The neutron energy threshold of detection at a given temperature will thus depend on the critical radius of the bubble and the stopping power of the secondary charged particle.

EXPERIMENTAL METHODS

Two APDs were purchased from Apfel Enterprises as part of a production preview program.

Two batches, each consisting of thirty cartridges, were also purchased. The cartridges in Batch 1 were used within a month of their arrival, whereas the Batch 2 cartridges were stored in the refrigerator for about seven months prior to usage. According to the manufacturer, the lifetime of these cartridges exceeds four months. Each cartridge has its own storage cap. When the cap is removed, the pressure is released, and the cartridge is "sensitised" or ready for use. The cartridges in Batch 1 could be used for as long as one week after sensitisation, while those in Batch 2 could be used for as long as three days.

The cartridges were stored in the refrigerator when not in use. Shortly before use, they were taken out of the refrigerator and allowed to equilibrate with the ambient thermal environment.

Each 4 ml glass cartridge contains about 0.03 ml of Freon 12 (CCl_2F_2; boiling point = −29.8°C) droplets suspended under pressure in a host mixture. The host mixture, either a polymer or a mixture of water, glycerine and gel, holds the drops such that when one drop evaporates it will not trigger other drops.

All neutron irradiations were performed outdoors in a low-scatter environment with the APDs mounted on a water phantom. Corrections for anisotropy of the neutron sources were made in calculating the neutron fluences. The fluences were then converted to dose equivalents using the methods outlined in NCRP 79.[5] Corrections for neutron scatter also were applied. The calculated values of the dose equivalent are reported.

A thermometer probe mounted on the phantom adjacent to the APD monitored the ambient temperature. The temperature and detector readings were taken at intervals of 5 to 10 minutes. Temperature corrections were applied to all data using the temperature dependence curve (for AmBe neutrons) supplied by the manufacturer. According to this, the sensitivity increases by about 5% per °C.

The photon exposures were made at a dose rate of 4.8 Gy/min with a Clinac 1800 medical accelerator. An APD was placed on the treatment couch inside the primary beam in the patient plane. A field size of 35 cm × 35 cm was used. Another APD was placed outside the beam at a distance of 50 cm from the isocenter in the patient plane. The electron exposures were also made in a similar manner but at a dose rate of 3.8 Gy/min with the Clinac 1800. A field size of 25 cm × 25 cm was used. The APD outside the beam was at a distance of about 30 cm from the isocenter, in the patient plane.

RESULTS AND DISCUSSION

Background

The average background on sensitised unirradiated detectors (Batch 2) varied from 0 to 4 counts in one day. This is in agreement with the manufacturer's claim of 1 to 5 counts per day. Because the APD has such a low background, no background subtraction was made in the data reported.

Linearity and reproducibility

Figure 1 shows the response of 5 APD cartridges when exposed to 0.83 mSv/h of PuBe neutrons. The solid line provided by the manufacturer shows the expected response to 0.29 mSv/h of AmBe at 23°C. The response is generally linear up to about 0.40 mSv with large variations between some cartridges and from the expected response at higher dose equivalents.

Response to neutron sources

The bubble detectors were exposed to neutrons from standard sources, bare ^{252}Cf, PuBe, PuB, PuF, and PuLi, with average energies of 2.15, 4.5, 2.1, 1.5, and 0.5 MeV, respectively.

Figure 2 shows the response of the APDs to ^{252}Cf and PuBe at dose equivalent rates of 1.1 and 1.23 mSv/h, respectively. The response to PuBe and ^{252}Cf closely follows the expected response to AmBe (0.29 mSv/h). Detectors also were exposed to about 0.08 mSv of PuBe, PuB, PuF, and PuLi neutrons at a dose equivalent rate of about 0.04 mSv/h. Two cartridges were used per irradiation condition. The results are shown in Table 1. The relative sensitivity is the ratio of the sensitivity in the linear region to the expected sensitivity (to AmBe neutrons) claimed by the manufacturer. The response to these different neutron sources is within 40% of the expected response.

Effect of temperature

Unirradiated detectors self-nucleate when heated to temperatures of 46°C or greater.

Effect of storage

After storage for seven months in the refrigerator, some cartridges retained their expected response to neutrons, while others had a lowered response.

Effect of photon irradiation

The APD is insensitive to low-energy photons. This was confirmed by exposing the detector to 12 Gy of ^{60}Co gamma rays. No effect was observed. At low energies, the photons interact mainly with the electrons and are therefore not very efficient at depositing their energy locally.[6]

The effect of higher-energy photons was studied by exposing the APDs both inside and outside the primary bremsstrahlung beam produced by 6 MeV and 15 MeV electrons. The results are shown in Table 2. Two cartridges were used for the 6 MeV exposure. The response inside the beam can be attributed to protons generated by the photodisintegration of deuterium in hydrogen. Hydrogen is a constituent of the detector medium. The isotopic abundance of deuterium is 0.015%. This reaction has an energy threshold of 2.22 MeV.

Accelerators operating above 10 MeV produce significant quantities of photoneutrons. At these energies, other photonuclear reactions also are possible. Since the response inside and outside the beam is practically the same, most of the response at 15 MeV can be attributed to the photoneutrons produced in the accelerator. The same cartridge was used for both the 0.5 and 1.5 Gy exposures. The lower readings for the 5 Gy exposure reflects the nonlinearity of the APD response. Cartridges from Batch 2 were used for these exposures.

Effect of electron irradiation

Table 3 shows the results of exposure to electrons of energies 12, 16, and 20 MeV from a Clinac 1800 medical accelerator. The response inside the beam can be attributed to the scattering of nuclei in the detector medium by these relativistic electrons. Only one cartridge (from Batch 2) was used at each energy. At 12 MeV, the same cartridge was used for both the 2 and 4 Gy exposures. At 20 MeV, the same cartridge was used for the 0.05 and 0.5 Gy exposures. No significant response above background was observed for the detectors outside the primary beam. Response to electrons in the energy range of 9 to 20 MeV also has been observed in the Chalk River Nuclear Laboratories neutron bubble detector.[7]

CONCLUSIONS

The APD has some desirable characteristics, such as its quick and easy readout, low background and insensitivity to low-energy photons.

The detector is sensitive to high-energy photons and electrons. Response to ^{252}Cf and PuBe neutrons closely follows the expected response (to AmBe neutrons) claimed by the manufacturer. At low dose equivalents, the response to PuBe, PuB, PuF, and PuLi neutron sources is within 40% of the expected response.

The detector self-nucleates when heated to temperatures of 46°C or greater. The dependence of sensitivity upon temperature is a limiting factor in the practical aspects of dosimetry. Other disadvantages include the large variations sometimes observed between cartridges and the limited range of linearity of response. These results were obtained with the 1988 production prototype detectors. Since then, according to the manufacturer,[8] there has been considerable improvement in the dynamic and linear range of the detector. The manufacturer also claims that the new cartridges can be used up to four weeks after sensitisation.

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FIGURE CAPTIONS

1. Linearity and reproducibility.
2. Exposure to PuBe and ^{252}Cf.

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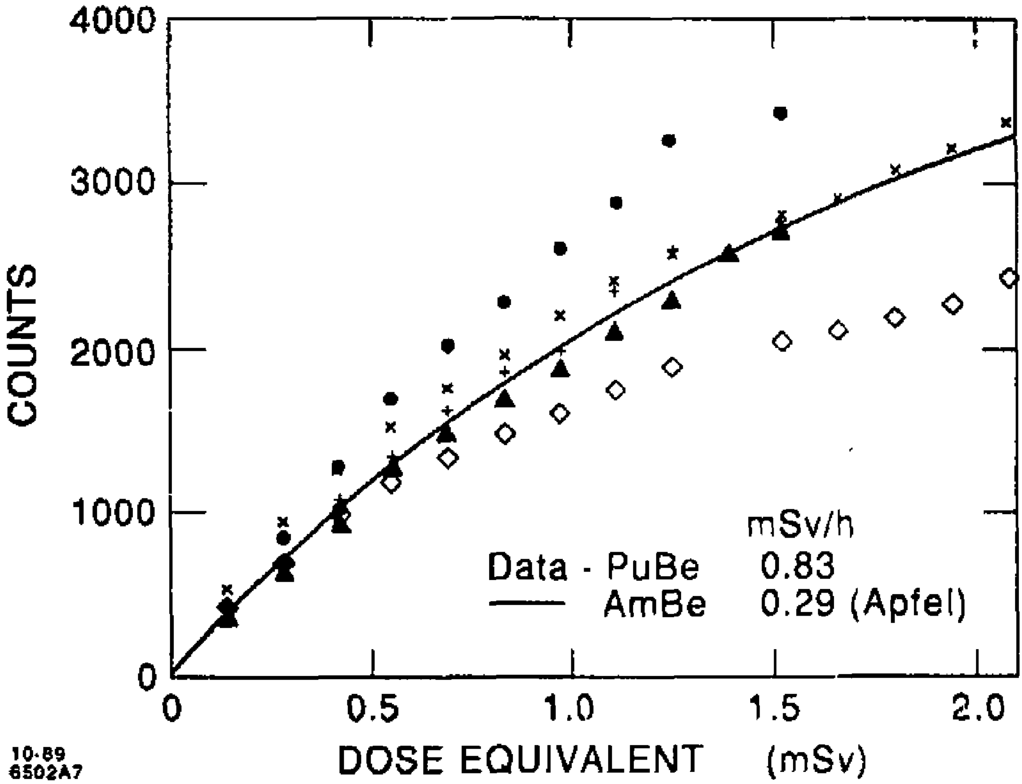

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0.5
1.0
1.5
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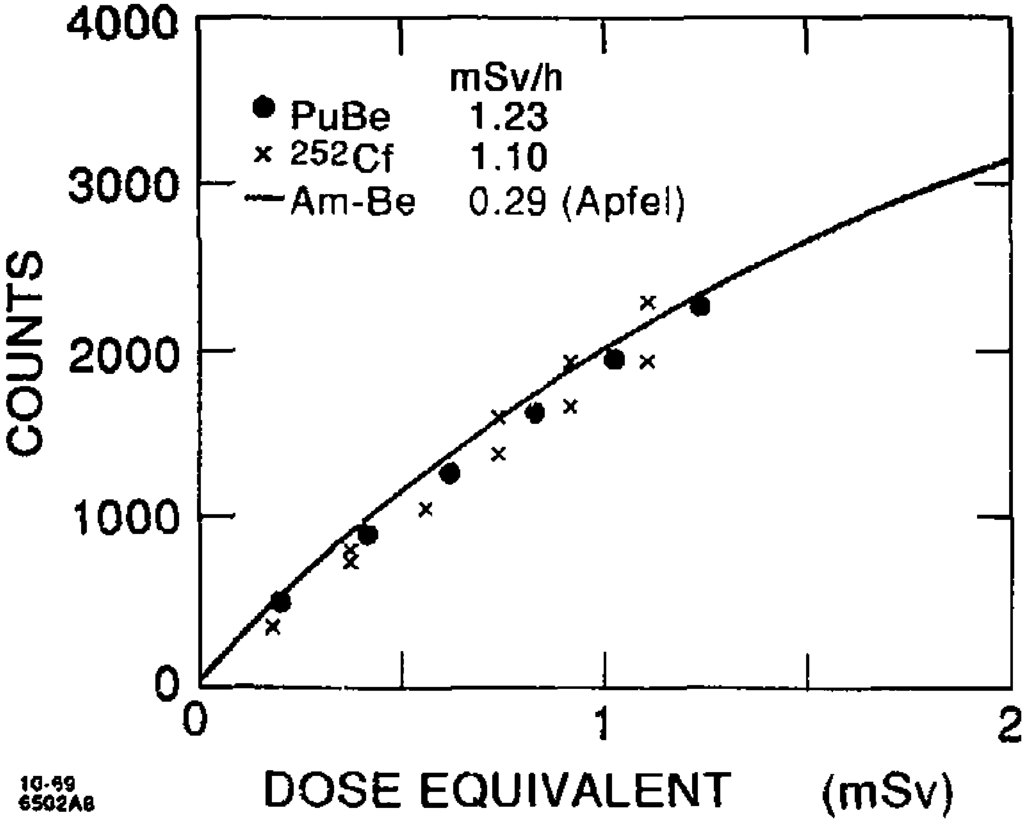
DOSE EQUIVALENT (mSv)
mSv/h
Data - PuBe 0.83
AmBe 0.29 (Apfel)
10-89
6502A7

Fig. 1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mSv/h
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252Cf 1.10
Am-Be 0.29 (Apfel)
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1
2
DOSE EQUIVALENT (mSv)
10-89
6502A8

Fig. 2

Table 1

Response to Neutron Sources

Source	Average Energy (MeV)	Relative Sensitivity	
PuBe	4.2	1.28	1.41
PuB	2.1	1.13	1.17
PuF	1.5	1.10	1.05
PuLi	0.5	1.30	1.29

Table 2

Effect of Photon Irradiation

Energy (MeV)	Dose Inside Beam (Gy)	Counts/Gy	
		Inside Beam	Outside Beam
6	5 5	41 27	1.6 0.8
15	0.5 1.5 5	206 197 111	214 208 85

Table 3

Effect of Electron Irradiation

Energy (MeV)	Dose Inside Beam (Gy)	Counts/Gy	
		Inside Beam	Outside Beam
12	2 4	23 21	0.5 0.25
16	1	121	4
20	0.05 0.5	180 206	0 0