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Study on bubble detectors used as personal neutron dosimeters

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ABSTRACT

Neutron bubble detector is so far the only personal neutron dosimeter satisfying the energy response criteria of the International Committee of Radiation Protection 60 (ICRP 60). This paper presents our studies on neutron bubble detectors including the manufacture, the relevant equipments, the basic calibrations and on-site tests for monitoring personal neutron dose. The results of calibrations show that the highest sensitivity so far manufactured by the authors reaches about 4 bubbles/μSv, the correlation coefficient of dose response is 0.99, and the in-batch consistency and reproducibility are up to the ISO standards. The results of on-site test show that the in-batch consistency and between-batch consistency are within 15% relative standard uncertainty. The results are directly readable. The detectors are portable, especially suitable for on-site neutron dose monitoring in n–γ mixed radiation fields.

1. Introduction

Neutron bubble detector is the only personal neutron dosimeter, which has adequate neutron energy response to meet the ICRP 60 recommendations for neutron dosimeter (Apfel and Roy, 1985a; D'Errico and Alberts, 1994). It has the advantages of real-time monitoring of neutron dose, stable energy response over a wide range of neutron energy (100 keV–15 MeV), low energy threshold, very low detection limit, high detection sensitivity, portability, visual reading, repeatable use and so on. It has become a significant and promising tool for neutron dose monitoring in a wide range of applications.

Neutron bubble detector consists of an elastic condensate, throughout which microdroplets of superheated liquid are uniformly dispersed. The detector is sensitized by unscrewing the piston in the counter-clockwise direction. When neutrons pass through a bubble detector and the microdroplets suffer neutron interactions, energetic charged particles produced in the bubble detector material by either recoil or nuclear reactions may deposit energy on the superheated droplets, induce their explosion and form bubbles. These visual and readable bubbles are the measure of the neutron dose.

The use of superheated drops dispersed in viscous gel was first suggested and investigated by Apfel in 1979 (Apfel, 1979) for the detection of particle radiations. Ing and Birnboim (1984) were the first to use a firm solid polymer instead of viscous gel and then they named the new version as bubble damage detector. SDD-100 neutron bubble detectors produced by Bubble Technology Industry (BTI) company had an energy response over the energy range of interest in radiation protection (D'Errico and Alberts, 1994). Recent investigations on the physics of these detectors led to a unified description of their fundamental properties (Apfel and Roy, 1984; Apfel et al., 1985b; Das et al., 2000a, 2000b, 2001; D'Errico, 1999; Glaser, 1952; Ing et al., 1997; Roy et al., 1987; Roy, 2001; Seitz, 1958). Since 1979, superheated emulsions have been employed as personal dosimeters, survey meters, area monitors and spectrometers in a variety of fields ranging from radiation safety (Apfel and Lo, 1989; D'Errico and Alberts, 1994; D'Errico et al., 1995, 1997, 1998a, 1998b; Ing et al., 1996; Ing and Mortimer, 1994; Nath et al., 1993; Roy and Sandison, 2000) to the detection of dark matter (Collar, 1996; Hamel et al., 1997). These detectors attracted the attention of scientists in China Institute of Atomic Energy (CIAE), where they started investigations on bubble detectors in 1989 (Guo, 2006).

In search for a low-cost, better performance and free from the complicated cryogenic system, a new prescription with a new process dedicated to neutron bubble detector production was developed. This paper presents our investigation in the manufacture of bubble detector including the refrigerants, the process and relevant equipments. In addition, the basic calibrations of these detectors in laboratory and on-site measurements are briefly described.

2. Preparation of bubble detectors

Aiming at the manufacture of bubble detectors with low-cost, better performance and free from the complicated cryogenic equipment, a new process has been developed since 2004 with a new prescription, a new pressure reactor (300 ml, 10 bar) and

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a new process completely under room temperature and high pressure, instead of low temperature and atmospheric pressure used previously (Guo, 2006).

2.1. Pressure reactor

A reactor withstanding 10 bar pressure has been installed. The pressure reactor houses a variable-speed magnetic stirrer, heating and cooling elements and a device for the addition and dispersion of composite superheated liquid R500 (dichlorodifluoromethane+difluoroethane). The reactor's container, made of transparent polymer, not only guarantees the safety of operation personnel, but also allows the reaction situation inside the reactor observed from outside throughout the manufacture process. A rotating lid on the surface of the condensate matrix brought to bear a given pressure on the top of condensate matrix. A nitrogen cylinder was connected with the reactor to provide another means of exerting pressure to compensate for the pressure losses as the reactants being distributed into detectors. The pressure gage mounted at the bottom (Fig. 1) displays the pressure inside the reactor anytime during the polymerization of the condensate matrix, and can be replaced by a plate made of high-density silica gel from which the superheated liquid can be injected into the sealed reactor by a syringe.

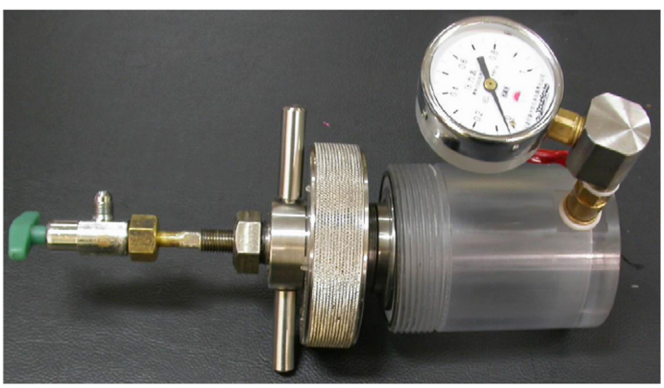

Fig. 1. Photo of pressure reactor.

2.2. Device for addition and dispersion of superheated liquid

Quantitative addition of μL level of superheated liquid into the condensate matrix is the key to achieve satisfactory reproducibility of the detector. A computer-controlled equipment for the addition and dispersion of superheated liquid has been developed and installed. The superheated liquid with the boiling point higher than −50 °C can be quantitatively (from 0.1 μL to 2 mL, with a relative uncertainty of <20%) transferred from the high pressure liquid-storing cylinder into the sealed reactor. It consists of a micro-motor, a driver, power supplies, a scale syringe, a linkage device and a control system. There are up to 7 programs stored in the driver, which can make the motor rotating clockwise or counterclockwise and make the injection of the superheated droplets automatic and quantitative.

2.3. New flow of detector production

A flow sheet of detector manufacture is shown in Fig. 2. The fabrication of a detector containing up to 0.08% superheated liquid starts with the preparation of a suitable condensate matrix. A composite refrigerant liquid R500 (dichlorodifluoromethane+difluoroethane) is selected as the superheated liquid. The resulting mixture is outgassed and kept at a temperature above its boiling point in the reactor. The refrigerant should be injected into the condensate matrix when the ambient pressure is greater than the vapor pressure of refrigerant to avoid boiling during the ensuing vigorous stirring. After droplets are dispersed to the radius of about 30 μm by a high-shear variable speed magnetic stirrer, cooled to 20 °C and set for half an hour, the superheated liquid drops were distributed in the condensate matrix homogeneously. The detectors are kept at 20±1 °C and pressurized to 5±1 bar during storage to keep them insensitive. The detectors can be used repeatedly by recompression on the top of the detectors, to

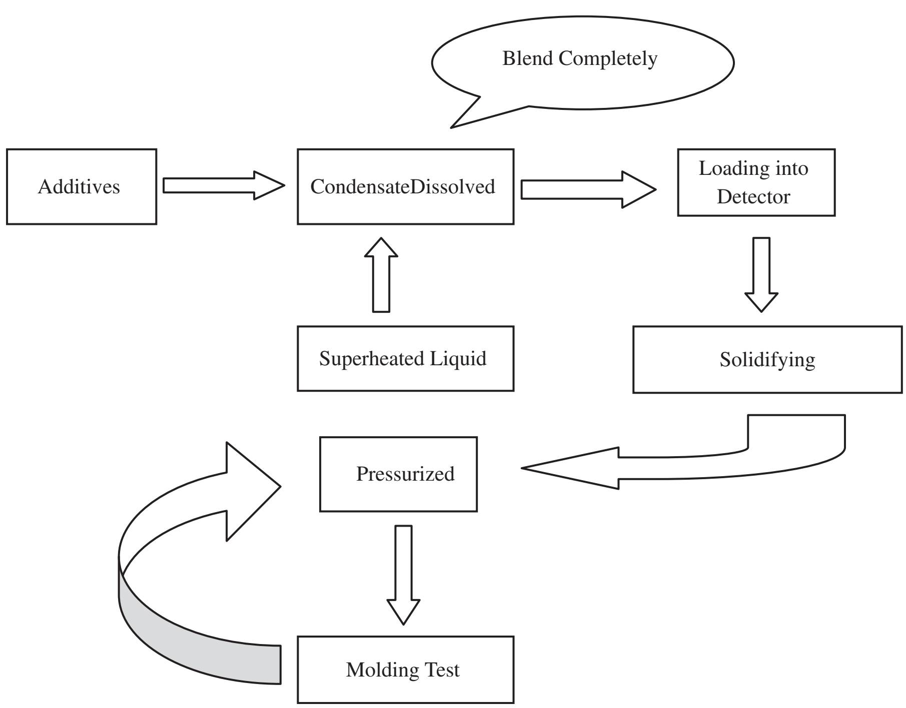

Fig. 2. Flow sheet of bubble detector fabrication.