DEVELOPMENT OF ^{3}He-^{4}He DUAL TYPE IONIZATION CHAMBER APPLICABLE TO n-X MIXED FIELDS

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Abstract

In order to monitor mixed neutron and X-ray fields associated with nuclear fusion experiments, a dual type ionization chamber system using ^{3}He and ^{4}He is under development. Several response characteristics has been tested with different radiation sources.

Introduction

In high temperature plasma experiments for fusion studies it should be very important from the radiation protection point of view to monitor and control the produced radiations in and around the experimental zone. These radiations are usually in the form of mixed n-X fields and generated as intermittent pulse bursts associated with plasma shots. A typical operational condition is such that several-to-ten sec plasma shots are given repeatedly in every ten minutes or so. It is, therefore, quite desirable to develop a monitoring sensor effective for real-time measuements of neutron components and X-rays separately.[1] For that purpose we have designed and tested a dual type ionization chamber system to be used as area monitors around the coming Large Helical Device (LHD) of NIFS.[2] This might also be applicable to other cases, for instance, radiation fields surrounding accelerator experiments.

Instrumentation

As the radiation dose sensor we have adopted the ionization chamber scheme to obtain the response in the current form, since it is required to cover a rather wide range of neutron fluence levels, sometimes accompanied by much stronger X-ray components, without suffering from the pile-up counting failure. In order to distinguish neutron contributions from X-rays, a dual-chamber system is proposed, which is consisting of a pair of cylindrical ionizing gas cells with the same size, shape, volume and wall material. One of the cells is filled with ^{3}He gas, sensitive to both n and X, and the other with ^{4}He gas, sensitive only to X-rays. We can, therefore, expect approximately equal responses to X-rays from the two cells, so that the neutron signals superposed on the ^{3}He response may be deduced by subtraction.

A chamber cell (80 mm $\phi \times$ 200 mm) is made of stailess steel of 3 mm thick, and an axial electrode (5 mm$\phi \times$ 150 mm) is held inside with a guard ring structure installed in one end of the cylinder. (Fig. 1) Between the electrode and the cell-wall is supplied an electric potential. The charge accumulated from the electrode is introduced to a capacitance vibrating electrometer to give the current output. With a moderate time constant the measurable currents are ranging $10^{-6} \sim 10^{-14}$ A. In the test experiments, each cell of the pair is connected with its own electrometer to avoid unexpected interference.

The characteristics of the ionizination chambers have been tested in several different conditions. Chamber cells with ^{3}He and ^{4}He gases filled at pressures of 1, 2, 3, 4 and 6 atm are prepared, as well as 1-atm air and 1-atm N_2 filled ones for comparison. If the neutron signals are due to a thermal capture process (n + ^{3}He $\rightarrow$ t + p + 765 keV), the stopping range of the secondary p and t in 1-atm ^{3}He gas are estimsated as 4.5 cm and 2.2 cm, respectivdly. Since we are interested in neutron energies up to a few MeV, chamber cells are usually surrounded by a 5cm thick detachable polyethylene moderator. The whole system is situated in a noise shielding casing of 1 mm thick Cu plate.

Test experiments have been carried out by using different radiation sources: ^{60}Co weak source, ^{60}Co strong source, ^{252}Cf, D_2O-thermalised reactor neutrons, and pulsed n-X fields in the neighborhood of an electron linear accelerator. Some of the preliminary results are given in the following.

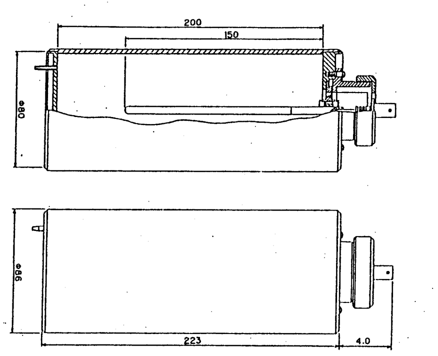

Fig. 1. Structure of cylindrical chamber cell

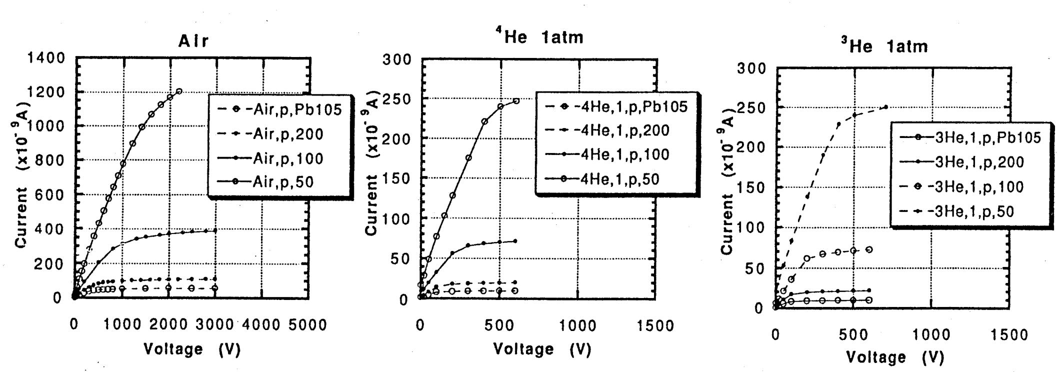

Fig. 2. Ionization chamber saturation curves (outward positive potentials)

^{60}Co-experiment

The response characteristics of the chamber to energetic photons have been surveyed by means of ^{60}Co gamma ray irradiation. A test field is available at the Cobalt Gamma Irradiation Facility (Dept. Nuclear Engineering, Nagoya University), where a strong ^{60}Co source (a few kCi) is installed.

The output current from an irradiated chamber cell will depend on such quantities as the applied potential and its polarity, the filling gas species and its pressure, the incident radiation energy and the source intensity.[3]

In varying the applied potential (V) to the outer cell wall (relative to the inner electrode), the electrometer output current (I) is observed to form the so-called saturation curve. Fig. 2 shows current behaviors from the 1-atm air, ^{3}He and ^{4}He cells at different source distances (50, 100, 200 cm and 105 cm with Pb shield) with outward positive potentials. Responses of ^{3}He and ^{4}He are quite similar to each other but much less than that of air. In Fig.3 are shown the saturation curves for 3-atm ^{3}He and ^{4}He in both polarity cases. The slower increase in I for outward positive potential case may reflect the possible space charge effects around the axial electrode as well as the recombination processes in the ion collecting efficiency. Pressure dependence of the saturation current level (I_s) is given in Fig. 4. There seems to hold good proportionality as expected.

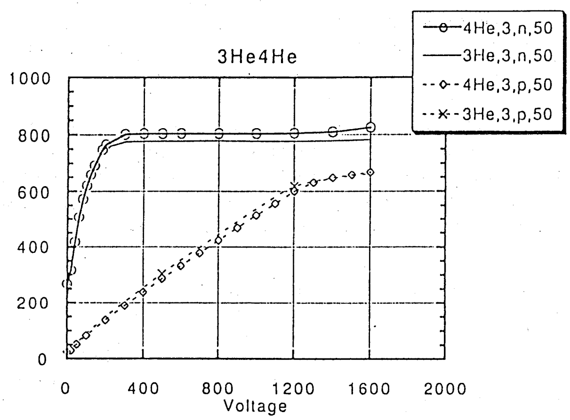

Fig. 3. Saturation curve for 3-atm ^{3}He and ^{4}He (distance from the source : 50 cm)

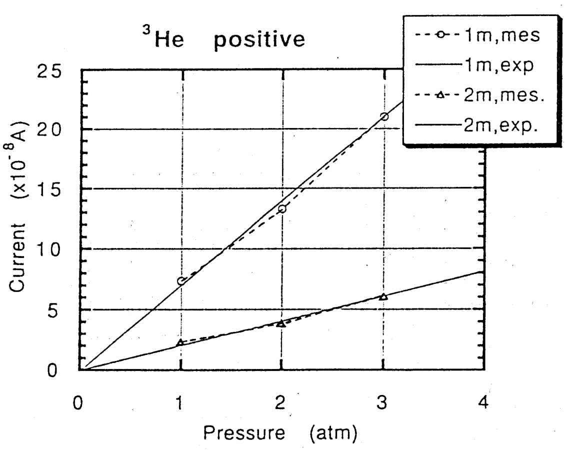

Fig. 4. Saturation current vs. gas pressure

The field intensity is varied by means of changing the source distance in the Irradiation Facility, where the exposure rate is ranging $10^{3} \sim 10^{5}$ R/h, and we found that the typical response currents from ^{4}He (1 atm) may be of the order of $10^{-8} \sim 10^{-6}$ A.

In comparison with such strong source data, we have also tried to make another exposure test by use of a much weaker source of mCi regime in an open space. This is corresponding to $10^{-3} \sim 10^{-1}$ R/h exposure rate and is giving a ^{4}He current output level of $10^{-14} \sim 10^{-12}$ A, which is almost the lowest detectable limit of the present system. As is given in Fig. 5, an apparent linear relation is attained to cover 8 orders of magnitude.

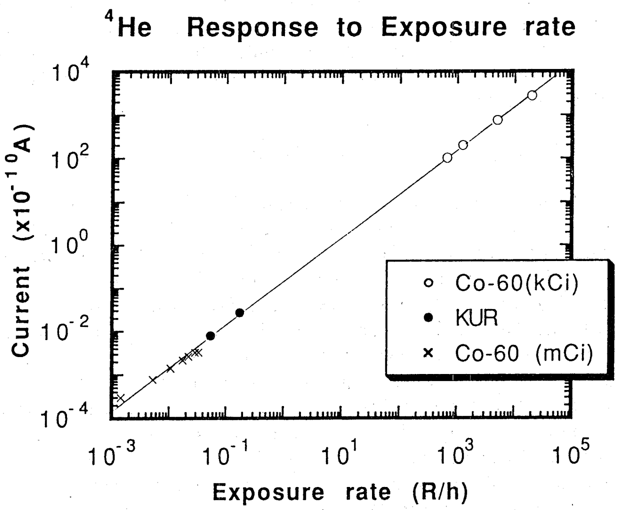

Fig. 5. Current from ^{4}He chamber vs. exposure rate

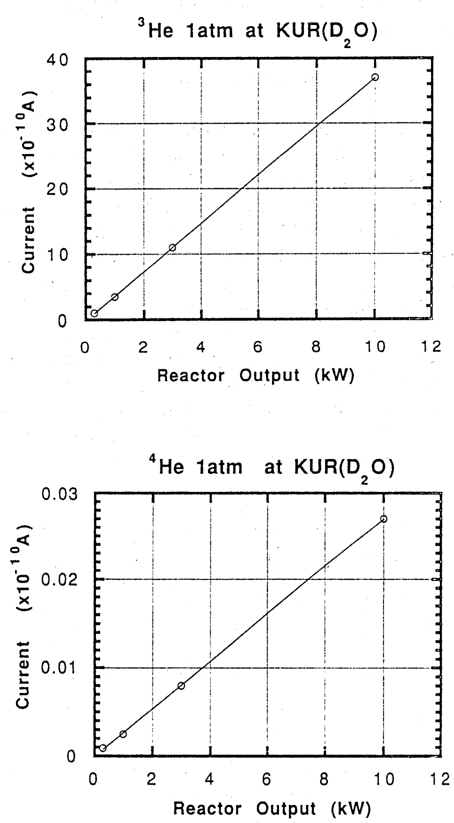

Fig. 6. Current responses in KUR thermal neutron field

Reactor neutron irradiation

A steady thermal neutron flux is useful to estimate the neutron sensitivity of the present chamber system. Test runs have been carried out at the D_2O-thermalised neutron facility of the KUR fission reactor (Research Reactor Institute, Kyoto University), where a good thermal neutron flux with very small contamination of gamma rays is supplied.

The results are summarised in Fig. 6, where the currents from the chambers, ^{3}He and ^{4}He, are shown against the reactor power, operations being done at 0.3, 1, 3 and 10 kW. Both chamber responses are excellently proportional to the reactor power, but their values are quite different. The ^{3}He current is in a regime of 10^{-9} A, while the ^{4}He giving 10^{-12} A. This shows us how low gamma ray condition is realised in the facility area. In the case of 3 kw and 10 kW operations, an area monitor (Aloka ICS-311) was set up inside the irradiation area, so that the exposure rates are known. The current read-outs from ^{4}He chamber are plotted in Fig. 5 together with ^{60}Co data, to show very good fitting.

Since the thermal neutron flux inside the facility area is estimated by other measurement as 9.6×10^3 n/cm^{2}s at 1 kW operation,[4] the observed ^{3}He current 0.35×10^{-9} A in this case implies the sensitivity for thermal neutrons to be 3.6×10^{-14} A/n cm^{-2} s^{-1} (with moderator).

When placed in this thermal neutron environment, the effect of polyethylene moderator (5 cm thick to cover side face and one bottom end of the cylinder) was found to reduce the ^{3}He signals by a factor of 6.5.

^{252}Cf-experiment

As a preliminary operation test in mixed n-X field , responses of the present dual chamber system to ^{252}Cf radiation fields have been examined. The available source is estimated to contain some 0.067 μg of ^{252}Cf isotope. This amount will give a neutron emission rate of 1.55×10^5 n/s and a gamma exposure rate of 9.5×10^{-6} R/h at 1 m from the source.

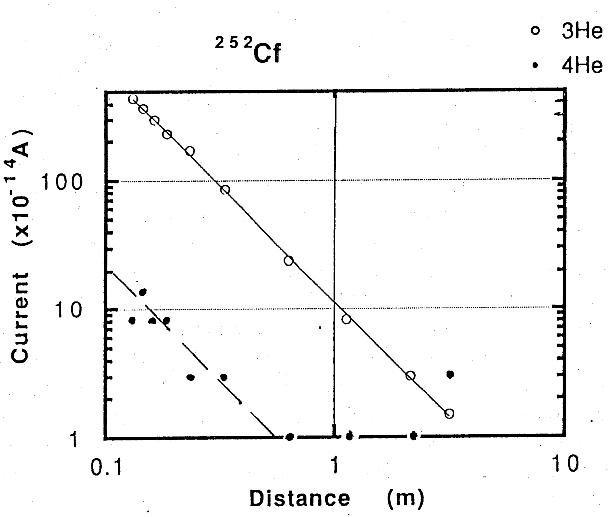

Fig. 7. Chamber responses in ^{252}Cf field versus source distance

Fig. 7 shows the response current dependence of ^{3}He and ^{4}He on the source distance. The decrease of ^{3}He signals with distance x is described as $x^{-1.8}$, whereas ^{4}He signals are generally low and much scattered in the regime less than several times 10^{-14} A, because of the instrumental measuring limit. The apparent ^{3}He/^{4}He signal ratios are ranging in 40 ~ 50, so that the subtraction of X-component is easily done in this case, except for faint signal region beyond 1 m.

These observed characteristics are not very different from those extrapolated from ^{60}Co and reactor experiments, though it is needed to make some more detailed comparisons.

Concluding remarks

The operational characteristics of ^{3}He - ^{4}He dual ionization chamber system has been checked and tested in various conditions. One of the main characteristics is the structure of the ion current saturation curve, which is depending on many parameters: gas species, pressure, field source specifications including energy spectrum and intensity, polarity and strength of applied potential, etc..

In the present study we have carried out steady state irradiation tests, using X (gamma)- rays from ^{60}Co source, thermalised neutron fluences from a reactor, and n-X mixed field from ^{252}Cf source. The preliminary results so far obtained are showing rather good sensitivity charactors as neutron detecting method, though there are still many problems left for later considerations.

The quantitative calibration on the read-outs of the chambers and the built-in data reduction (such as ^{3}He-^{4}He subtraction) systems should be further developed, as well as the conversion to the dose equivalent quantities. The chamber wall materials should be properly chosen from this point of view in the next step.

It is urgently important to make pulse-like irradiations, or experimental trials in busrst-like fields, for which applications the present system has been originally motivated. Possible testing experiments in the fields around an electron linac or some other accelerators are under consideration.

Acknoledgements

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Refernces

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