TRANSMISSION DETECTORS FOR CYCLOTRON in-vivo IRRADIATIONS WITH NEUTRONS

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Abstract

The neutron fluence imparted to the irradiated subjects needs to be measured accurately in order to obtain meaningful results from diagnostic irradiations. A convenient neutron detector for this purpose is in the form of a transmission chamber, which covers the whole beam directed at the subject. In one design the detector is an ionization chamber, filled with propane gas, in another a thin sheet of plastic scintillator is coupled to a pair of photomultipliers.

1. Neutron transmission detectors

The role of the neutron transmission detector is to provide information on the neutron flux passing through the sensitive contour of the device. The main requirements which such detectors should fulfil are stability and linearity, independence of readings from the beam profile distribution and a form that can be incorporated into the design of neutron collimators. The stability requirements are fairly severe, and in diagnostic neutron installations reproducibility better than 1% is often called for. To maintain such a high degree of reproducibility the detector, as a rule, requires a regular calibration by means of an isotopic neutron source. The required linearity is usually of a similar order, in the working range that may cover one or two decades of the flux intensity.

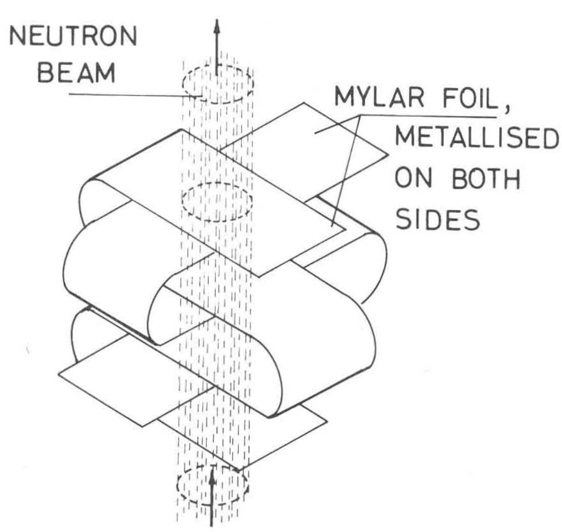

Fig. 1. Zig-zag arrangement of Mylar strips in the propane ionization chamber.

It would be an advantage to have a transmission detector that is insensitive to the neutron energy. This aim has not been achieved in the two designs described in this paper, but the variation of readings with energy are expected to be fairly low, so that changes in the neutron spectrum caused by the drift in the machine energy, deterioration of target etc. are of no consequence. Nevertheless, when the accelerated ion or target material is changed, the transmission chamber has to be recalibrated.

2. Propane ionization chamber

The propane ionization chamber has an electrode system in the form of two intertwined zig-zags of 40 μm thick Mylar strip, metallised on both sides. (Fig. 1). One of the zig-zags is four-fold, another is three-fold. The Mylar strip is tensioned with springs attached to its ends. The supporting structure is built on PTFE insulators (Fig. 2) and the whole assembly is placed inside the aluminium can. The whole chamber is 16 cm high and has the largest diameter of 31 cm. On the top of it there is a perspex jig to place the Am-Be source (1 curie) used for calibration and checking. (Fig. 3). The maximum beam diameter through the chamber is 13 cm. The metal lid and bottom of the chamber in the areas where the beam transverses it are thinned down to about 1 mm, in order to minimize the effects of scattering. The whole chamber is sealed with an 'O' ring and a series of bolts. Care has been taken to leak-proof the signal and EHT connectors. The chamber is filled with propane gas carefully dried by desiccator columns filled with a molecular sieve absorbent. The outlet of the chamber is connected to the "bubbler" filled with silicon oil. The chamber is connected to the biasing source of about 200 V and to the electrometer (Fig. 4).

It is very likely that the chamber could be completely sealed instead of operating with a gas flow system, assuming that a very reliable seal could be maintained for a long period.

The ionization chamber operates in the neutron flux density range of 10^3 to 10^8 n.cm^{-2}.sec^{-1} and the reproducibility over a period of few years is

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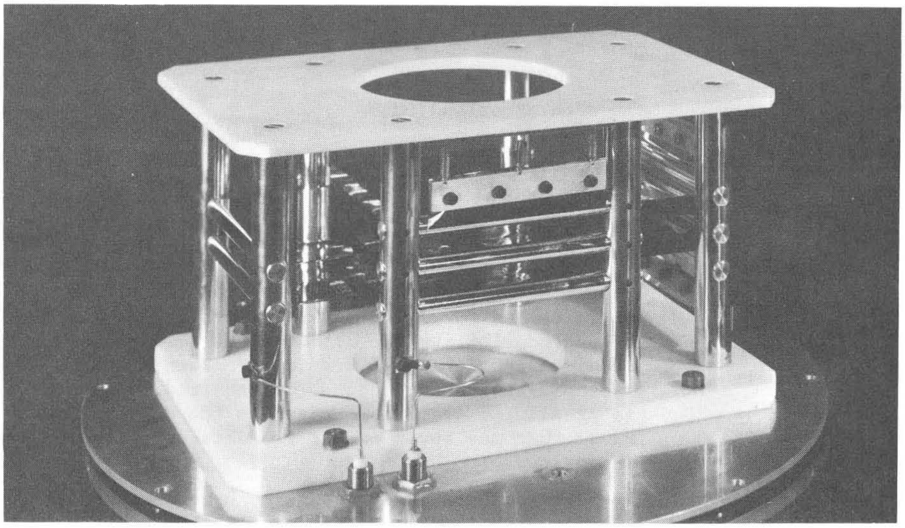

Fig. 2.
Interior of the propane chamber. Two PTFE insulators hold the pillars, to which the strip tensioning and positioning assembly is attached.

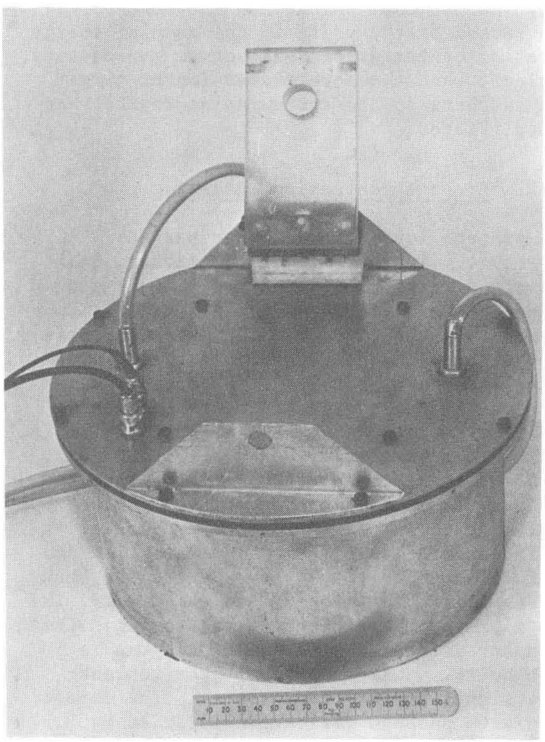

Fig. 3. The external appearance of the propane chamber. The calibration neutron source is placed in a perspex holder that can be flipped to lie flat on the top of the chamber. In use, the neutron beam transverses the chamber from the bottom to the top.

within 1%. The electrometer is of current-to-voltage converter type, built around operational amplifier model 310 J supplied by Analog Devices Ltd. The integration of the neutron flux into fluence is performed by the voltage-to-frequency converter employing the 15VF-1 module (supplied by ANCOM Ltd.) and a scaler. The front end of the electrometer is located within two meters of the chamber and is connected to the rest of electronics in the control room by a long multiwire cable. High stability current and voltage sources built into the electrometer, permit the checking of the operation of both the input amplifier and the V/f converter.

About 2/3 of the chamber current comes from the gas, the rest from the Mylar strip. For a neutron beam of average energy of 2.5 MeV and the flux of 10^4 n.cm.$^{-2}$.sec^{-1} the chamber current is about 200 pA.

3. Scintillation transmission detector

The second type of transmission detector uses a very thin (2mm) sheet of scintillator type NE 102A (Nuclear Enterprises Ltd.). The scintillator can be metallised, or one can rely on the internal reflections to bring light to the two PM tubes. The scintillator is in the form of a square, with perspex lightguides cemented on to the edges (Fig.5). The uniformity of response was checked with a small, collimated gamma source and was found to be within 3% in the beam transmission area. There is no doubt that more careful design of the beamguides can further improve the uniformity of response.

The DC output can be used as a measure of neutron flux, but a considerable reduction of gamma background can be attained if a very fast discriminator and scaler are used instead of an average current meter. The system can be employed for

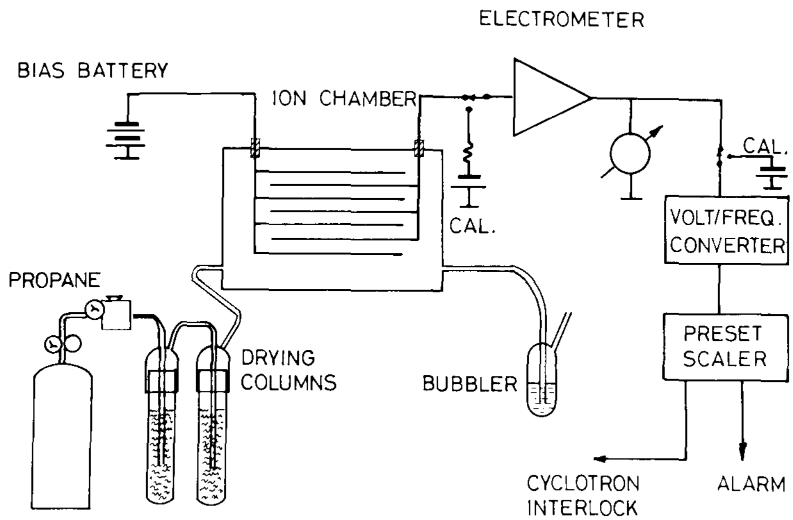

Fig. 4.

The propane transmission chamber installation. The present scaler can be used to terminate the irradiation on reaching the predetermined neutron fluence.

fluxes in the region of 10^2 - 10^7 n.cm^{-2}.sec^{-1} in the pulse counting mode, and in the region of 10^4-10^{10} n.cm^{-2}.sec^{-1} in the DC mode.(Fig.6 a & b).

The whole sheet scintillator was wrapped in two layers of black polyethylene, the detectors being mounted in metal shields. In this arrangement the transmission detector is extremely thin and can be placed in a very limited space. The stability of the scintillation transmission detector depends primarily on the stability of the EHT supply to the phototubes. It is also important to take note of the change of sensitivity with temperature, so that calibration with an isotopic source should be performed at the same temperature as the intended subsequent operation.

The energy response of the detector is a slowly changing monotonic function in the energy range employed for diagnostic and therapeutical irradiations (up to 30 MeV).

An improvement is possible in the design of the scintillation transmission detector if a pulse-shape discrimination can be incorporated. It calls for the development of very fast (more than 10^5 events per sec) shape discrimination circuitry, which is not available at this moment.

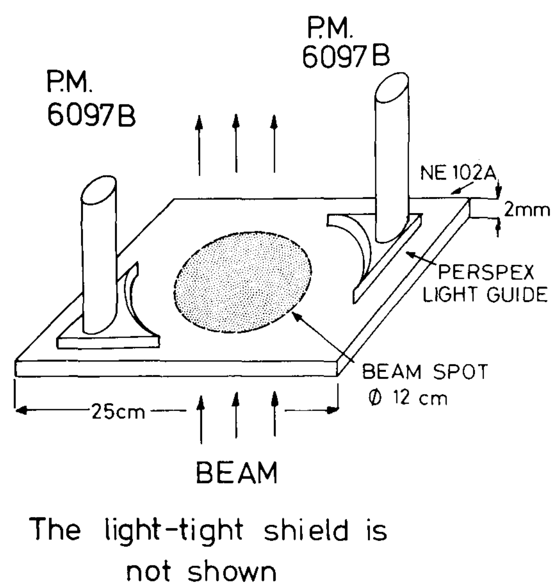

Fig. 5. Scintillation transmission detector.

4. Transmission chamber in use

The two transmission detectors have been constructed and tested in the Nuffield Cyclotron Laboratory in the University of Birmingham. One of them has been in regular use during the last four years in connection with in vivo diagnostic neutron irradiations. It has been installed inside a vertical collimator, as shown in fig. 7.

It was found in practice that the traces of moisture in the propane gas can affect the amount of "dark" current. Obviously, the residual current due to leakage can be compensated electronically without difficulty, but it is more reliable to reduce it to a very low value, so that any fluctuations are well below the other errors in the system. The silica gel alone is insufficient, as its pores tend to be clogged with propane. Use of the molecular sieve, which cannot absorb propane but absorbs water, is much more convenient.

The presence of large PTFE insulators inside the chamber leads to the appearance of surface charge effects. If the chamber has been "idle" for a prolonged time, then immediately after switching

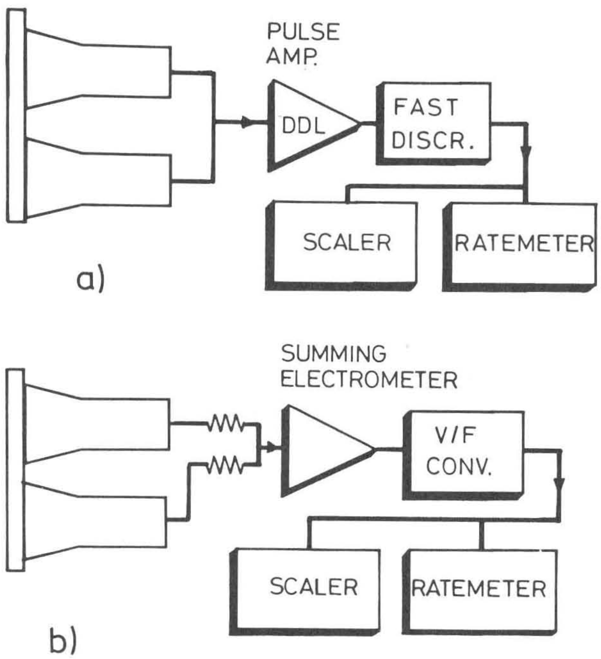

Fig.6. Electronics for scintillation transmission detector a. Pulse mode
b. DC mode

on, a surface charge forms on the surface of the insulators. This has an effect on the efficiency of collection of ions by the electrodes. An exposure of the chamber to the beam or to the calibration source quickly re-establishes the surface charges.

5. Energy response

The energy response of the transmission ionization chamber has not been determined, but it is evident that in the energy region below 12 MeV it must roughly follow the energy dependence of the (n,p) cross section. Measurements with track detectors on two types of neutron spectra, one produced by 10 MeV protons on lithium, another by 30 MeV ^{3}He on beryllium, indicate a drop in sensitivity for the more energetic second spectrum by a factor of about 2.

The energy response of the scintillation transmission detector in the pulse mode is a function of the discriminator threshold. The curves in fig.8 are based on those published by Rybakov and Sidorov, but have been corrected for the contribution of processes involving carbon nuclei at higher neutron energies.

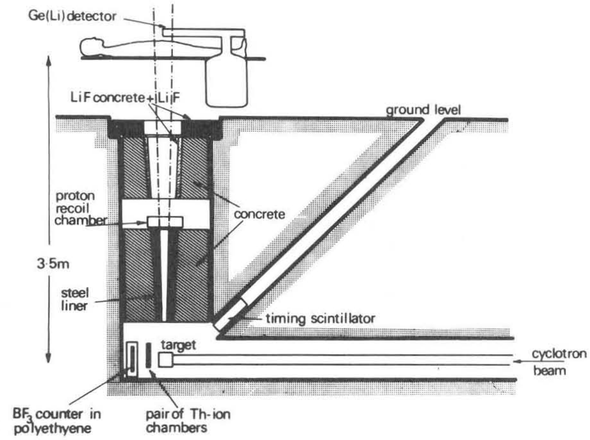

Fig. 7 Transmission chamber installed in the Nuffield Cyclotron Laboratory.

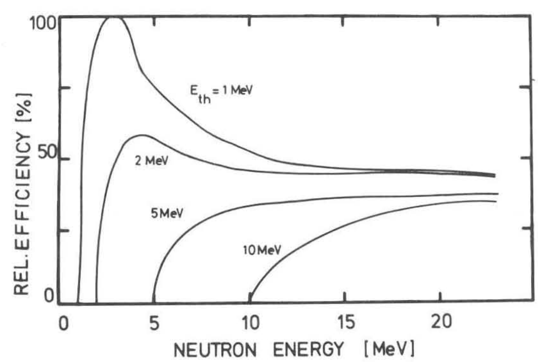

Fig. 8 The energy response (calculated) for a scintillation transmission detector as a function of discriminator threshold.

6. Acknowledgements

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7. Literature

1. Rybakov, B.V. and Sidorov, V.A. "Fast-neutron spectroscopy" English translation. Consultants Bureau Inc. New York 1960.