DEVELOPMENT OF GAS-FILLED POSITRON-SENSITIVE RADIODETECTORS

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INTRODUCTION

There is a need for further developments of specially designed radiodetectors for use in cyclotron/PET facilities. In this work we focused our attention to the development of a large-volume multiwire proportional counter for monitoring of airborne positron-emitting gases and a positron-sensitive low-voltage ionisation chamber for monitoring the absolute concentration of positron-emitters in flowing gases.

In the field of radiation detection cylindrical gas proportional counter tubes are extensively used due to their simplicity in design. The multiwire proportional counter was designed for measuring extremely low concentrations of airborne positron-emitting gases in surroundings where the maximum permissable concentration values in air (MPC_a-values) for the short-lived positron-emitters are likely to be occasionally exceeded. Typical areas of interest include radionuclide production facilities and radiochemistry laboratories where labelling syntheses with short- lived positron-emitters are carried out. Also PET facilities are of interest, especially when the short-lived oxygen-15 labelled gases are used in inhalation studies.

The design criterion of the low-voltage ionisation chamber was a high sensitivity to positron-emitting gases combined with a low sensitivity to 511 keV photon background radiation. This criterion is satisfied in an ionisation chamber where the chamber fill gas is composed of the radioactive positron-emitting gas itself. The ionisation chamber was designed for monitoring the absolute concentration of e.g. ^{15}O-labelled gases flowing in a gas transport line.

Large-Volume Multiwire Proportional Counter

The gas proportional counter was equipped with a cylindrical inner cathode and a coaxially positioned outer cylindrical cathode. An array of 21 NiCr-anode wires of 25 μm diameter was placed between the inner and outer cathodes in a cylindrical coaxial alignment with the cathodes to form a virtual cylindrical anode. The inner cylindrical cathode had a diameter of 55 mm and was made of aluminum machined to a wall thickness of 90 μm. The inner diameter of the outer cylindrical cathode was 75 mm. Room air was continuously sucked through the inner cathode with the help of a fan mounted in the outlet flange of the detector. The sensitive area of the radiodetector was 304 cm^2 and the active sampling volume 418 cm^3. Argon-methane P-10 (10 % methane/90 % argon) was used as the counter gas and was continuously flowing through the counter volume. A potential of 2.1 kV was applied on the NiCr- anode wires. Positrons created in the decay of the short-lived positron-emitters carbon-11, nitrogen-13 and oxygen- 15 penetrate the 90 μm thick aluminum inner cathode and cause ionisation of the argon fill gas. Free electrons created in the slowing down processes of the positrons are accelerated by the electric field around the anode wires. The small diameter of the anode wires intensify the electric fields proximate each wire causing avalanche multiplication of free electrons and inducing of a charge pulse which is measured with a Herfurth radiation monitor H 1395 B (Herfurth GmbH, Hamburg, FRG).

The GPC gave a linear response to carbon-11 concentrations up till 39 Bq/cm^3 (1.05 nCi/cm^3) in the 418 cm^3 active sampling volume of the detector. The background-count rate of the detector was 9 counts per second. The detection limit for carbon-11 was 45 Bq, which gave a net-count rate of 27 cps, or three times the background-count rate. For the 45 Bq amount of ^{11}C-radioactivity uniformly distributed in the active sampling volume of the detector, the detectable concentration limit for carbon-11 is 45 Bq/418 cm^3 = 0.11 Bq/cm^3 (3.0 pCi/cm^3).

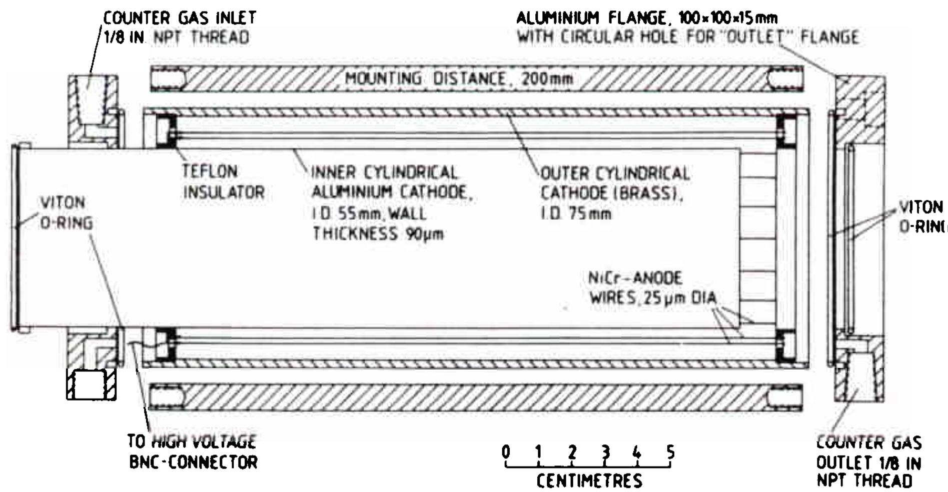

Figure 1 Cross-sectional views of inner and outer cylindrical cathodes and mounting flanges. NiCr-anode wires are placed in cylindrical coaxial alignment between the cathodes.

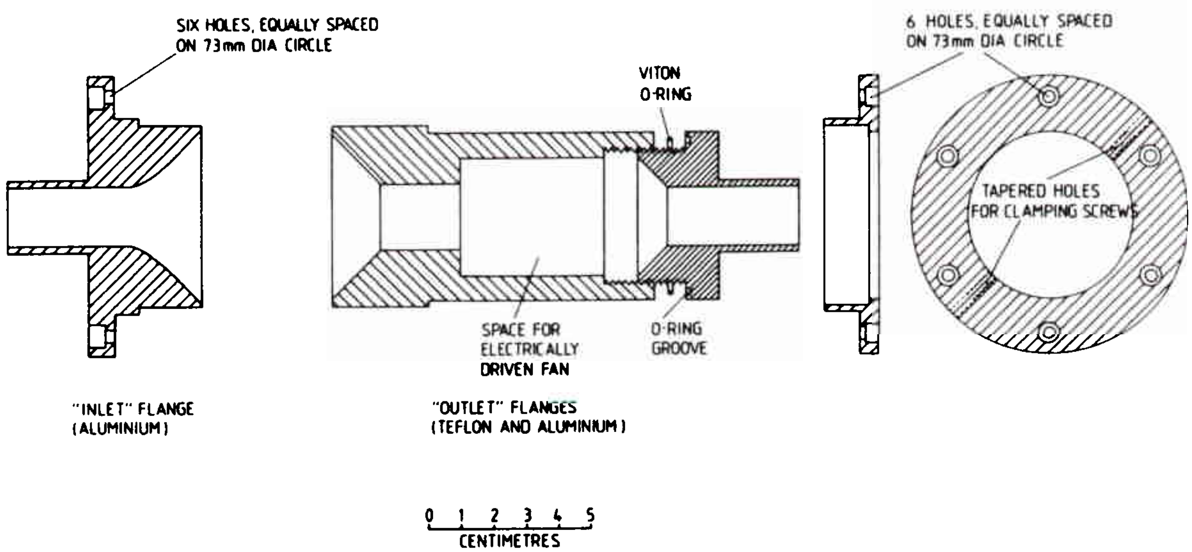

Figure 2 Cross-sectional views of "inlet" and "outlet" flanges.

The static efficiency of the gas proportional counter was 60% for carbon-11 in the region of linear detector response (Table I). The efficiency due to the 511 keV photons created in the positron annihilation was less than 0.5 %. In order to suppress the rise in the background- count rate due to high amounts of radioactivity in the vicinity of the detector or in patients undergoing PET-investigations, a massive lead shielding (thickness 8 cm) was built around the detector. The characteristics of the multi-anode gas proportional counter are summarized in Table I.

Table I Characteristics of multi-anode gas proportional counter.

- Multi-anode gas proportional counter
- 21 NiCr 80/20 anode wires (25 μm diameter) in cylindrical coaxial alignment with inner and outer cathodes
- Inner cathode: diameter 55 mm, wall thickness 90 μm, material: aluminum
- Outer cathode: inner diameter 75 mm, material: brass
- Counter gas: Argon-methane P-10 (10 % methane/90 % argon)
- Anode voltage: 2.1 kV (Plateau reached at 2.0 kV)
- Sensitive area of the detector 304 cm^2 *
- Active sampling volume of the detector: 418 cm^3 *
- Background-count rate: 9 cps
- Static efficiency for carbon-11 ($E_{\beta+,max}$ = 0.968 MeV): 60 %
- Detection limit for carbon-11:
  - 45 Bq (1.2 nCi)
  - 0.11 Bq/cm^3 (3.0 pCi/cm^3)
- Linear up till:
  - 16.5 kBq (0.45 μCi)
  - 39 Bq/cm^3 (1.05 nCi/cm^3)

* Calculations based on the active length of the counter.

Positron-Sensitive Low-Voltage Ionisation Chamber

Commercially available ionisation chambers are generally used in the routine production of radiopharmaceuticals labelled with short-lived positron-emitters. However, bulky shielding is often required in order to reduce the background radiation from highly radioactive sources in the vicinity of the radiodetector. Earlier we developed a low-voltage ionisation chamber based on the conventional ionisation chamber technique with the chamber fill gas separated from the radioactive gas to be measured.[1] In the present work we have developed a positron sensitive ionisation chamber operating with the radioactive positron-emitting gas as the chamber fill gas. This resulted in an ionisation chamber highly sensitive to positron-emitting gases and well suited for monitoring the absolute concentration of e.g. ^{15}O-labelled gases in a gas transport line.

In our special case where the ionisation chamber will be installed in a gas transport line for ^{15}O-labelled gases,[2] the ionisation chamber fill gas is composed of the target gas mixtures, nitrogen plus 1 % oxygen or 1 % carbon dioxide, containing the trace amounts of ^{15}O- labelled molecular oxygen or carbon dioxide, respectively produced in a target chamber mounted on the cyclotron beam line. The radioactive gas flows continuously through the ionisation chamber at a constant flow-rate and at a pressure slightly above the atmospheric pressure.

The commercially available electric components of the amplifier system were the same as those used in the ionisation chamber earlier developed.[1] The construction of the printed circuit board for the electric components and the components of the ionisation chamber (Figure 3) were done in-house. A five femtoampere bias current operational amplifier, Teledyne Philbrick parametric amplifier Model 1702,[3] was used to measure the mean ionisation current between the electrodes applied with a 15 V voltage supply, the inner electrode being the anode. The digital output was adjusted to directly display the concentration of β^+- radioactivity in the 2 cm^3 chamber volume in units of MBq/cm^3. A scheme of the arrangement of the inner and outer electrodes of the ionisation chamber is shown in Figure 3.

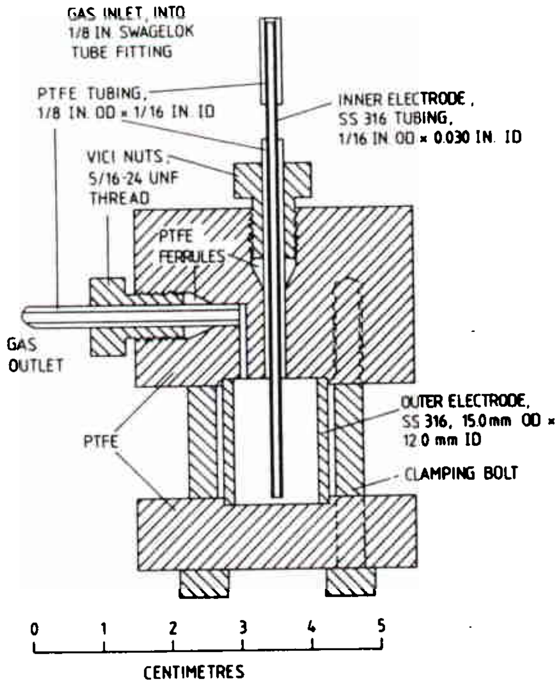

Figure 3 Cross-sectional view of low-voltage positron-sensitive ionisation chamber. The radioactive gas flows continuously at atmospheric pressure through the ionisation chamber

DISCUSSION

The multiwire gas proportional counter has been used in the evaluation of the extremely low concentration levels of nitrogen-13 and oxygen-15 produced through photonuclear reactions with the components of air in areas where radiation therapy is carried out with high-energy linear accelerators.[4] This multiwire proportional counter is a modified version of the proportional counter we developed for measuring the amount of [^{11}C] carbon dioxide in exhaled air in connection with PET- investigations.[5]

The low sensitivity of the low-voltage ionisation chamber to the 511 keV photon background radiation made lead shielding of the detector almost unnecessary. The ionisation chamber will be installed in the Turku University Central Hospital PET-laboratory in the far end of the 650 m gas line[2] used for the on-line transportation of ^{15}O-labelled gases from the Åbo Akademi Accelerator Laboratory.

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