^{3}He Proportional Counters

GENERAL DATA

General Description

^{3}He proportional counters utilise the ^{3}He(n,p)^{3}H reaction for the detection of neutrons. This reaction is of the type –

$$A + n + E_n \rightarrow B + C + (Q + E_n)$$

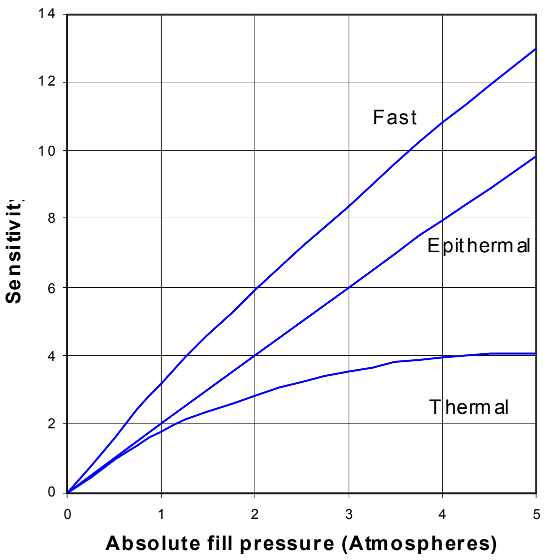
where

A is the original atom,
n is the neutron,
E_n is the neutron energy,
B and C are the product particles,
Q the reaction energy.

For thermal neutrons the reaction is as follows:-

$$He + n\ (thermal) \rightarrow {}^1H + {}^3H + 764\ KeV$$

The reaction energy of the ^{3}He reaction is only a quarter of that of the ^{10}B reaction utilised in BF_3 proportional counters. For this reason ^{3}He counters can be used as neutron spectrometers as well as simple neutron detectors. The high capture cross section of ^{3}He results in these counters being very sensitive neutron detectors.



The 'SENSITIVITY' scale is the sensitivity of a 25 mm diameter ^{3}He couter using a comparable BF_3 as a reference

Fig. 1

Construction

Centronic ^{3}He proportional counters are constructed using metal walls and specially manufactured metal-ceramic insulators. In the interest of long counter life and good resolution particular attention is paid to the removal of impurities from filling gases and other materials.

Tubular counters of 25 and 50 mm diameter are standard as are spherical ^{3}He counters for applications where omni-directional response is required.

Gas Filling

Before final filling is carried out, all counters are mass spectrometer leak tested and undergo evacuation, baking and purging processes.

The gas filling comprises a mixture of ^{3}He and other gases, typically krypton or carbon dioxide. This mixture can be selected to optimise specific aspects of performance, e.g. krypton gives best results for use in neutron spectroscopy, whereas carbon dioxide gives lower sensitivity to gamma radiation when counting thermal neutrons only. Fillings of up to 10 atmospheres are available as standard.

The sensitivity of the counter is dependant upon both the filling pressure and the energy of the neutrons being detected.

Figure 1 shows the sensitivity of a 25 mm diameter ^{3}He counter at various fill pressures. The sensitivity is expressed as a ratio to a comparable BF_3 counter. The BF_3 counter was of identical construction but filled to a constant 68 cm Hg pressure with BF_3 having 96% enrichment in the boron 10 isotope. The graph shows that this 25 mm ^{3}He counter, when filled to 4 atmospheres pressure, reaches 90% of its maximum sensitivity to thermal neutrons. There is little benefit in increasing fill pressure beyond this value, which has therefore become the most popular pressure for 25 mm counters. The corresponding pressures for 50 mm and 13 mm counters are 2 and 9 atmospheres respectively.

Sensitivity

For thermal neutrons the capture cross section of ^{3}He is 5400 barn, as compared to 4200 barn for boron 10. For both materials the capture cross section for thermal neutrons up to energies of 0.2 MeV follows a 1/v law where v is the neutron velocity.

The reduced cross section of ^{3}He at higher neutron velocities results in a characteristic for epithermal and fast neutrons which is nearly linear by comparison with that for thermal neutrons (see Fig. 1).

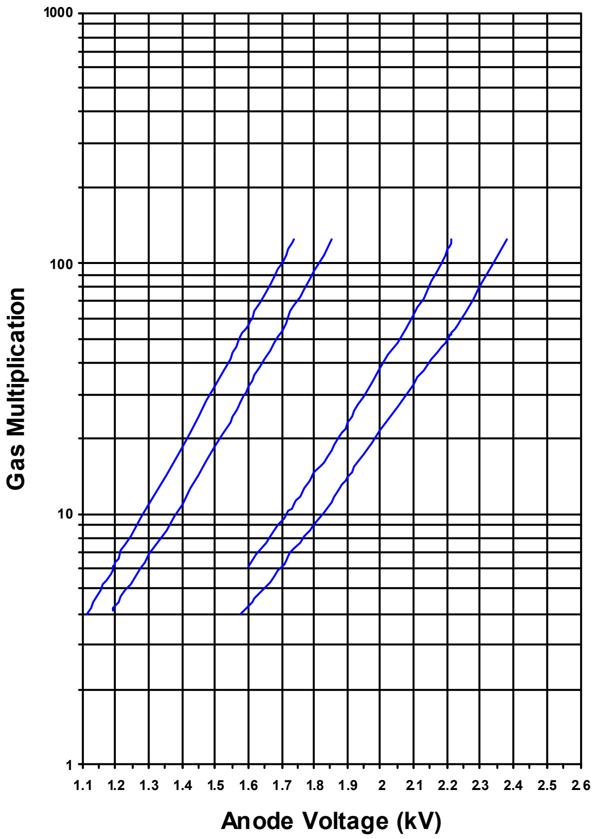


Fig. 2

It is therefore possible to obtain a large increase in sensitivity to epithermal and fast neutrons by use of increased filling pressures, but not for thermal neutrons. The curves for epithermal and fast neutrons would also reach a saturation level if the graph was continued but only at unrealistically high pressures.

Pulse Size and Gas Amplification

With the release of 764 KeV of energy in the neutron-^{3}He reaction (as stated in the introduction), and taking 35eV as the approximate ionisation potential of helium, the basic magnitude of the resulting pulse is 2.2×10^4 ion pairs = 3.5×10^{-15} Coulombs. It is therefore necessary to use gas multiplication in order to secure an adequate output pulse. Figure 2 gives the relationship between the gas multiplication and the applied anode potential for typical 25 mm and 50 mm counters as a function of filling pressure.

EHT Plateau

The length of the EHT plateau obtained depends upon the slope of the gas multiplication curve, the filling pressures and the geometry of the particular type of counter. The design of Centronic ^{3}He counters ensures that good EHT plateaux are achieved, extending over at least ± 10% of nominal operating EHT with a very small slope. Good plateau stability is retained at high temperature.

Operating ^{3}He Counters

Operating a ^{3}He counter is similar in many respects to operating a BF_3 counter, but a number of points should be observed if maximum performance is to be achieved.

a) *Gas multiplication*
The optimum resolution of any proportional counter system is a compromise between the gas multiplication in the counter and the electronic amplification. Calculations show that a gas amplification of about 20 is the most suitable value for ^{3}He counters. Centronic ^{3}He counters are tested to ensure that this order of gas multiplication can be achieved without significant breakdown pulses.

b) *Effects of Gamma Radiation*
No damage to ^{3}He counters from gamma radiation has been reported, but ^{3}He counters exhibit somewhat higher gamma sensitivity than BF_3 counters. In strong gamma fields large time constants as normally recommended will cause the many small gamma pulse charges in that time to be additive. They will then appear as one single pulse of such a magnitude that the discriminator cannot reject it. This phenomenon is known as 'pulse pile-up'. With short time constants however, ^{3}He counters can be operated in gamma fields up to typically one R/hour.

c) *Amplifier time constants*
The fact that the neutron-^{3}He reaction produces two product particles moving in different directions results in a long collection time for the resulting ionisation. Integrating and differentiating time constants of between 1 and 3 microseconds are recommended. It may be necessary to depart from this recommendation if the counter is operated at high counting rates, or in the presence of intense gamma radiation, in order to reduce pulse pile up. It must, however, be realised that some resolution is sacrificed under these conditions.

d) *Amplifier gain*
As stated in the section on pulse size and gas amplification, the basic charge from a ^{3}He (n,p) reaction is about 3.5×10^{-15} Coulombs. It should be noted that this is only approximately ¼ of the charge per pulse from a ^{10}B (n.α) reaction

Using a gas multiplication of about 20, an amplifier sensitivity capable of analysing pulses smaller than 7×10^{-14} Coulombs is desirable. This figure does not take into account any losses due to cable capacitance.

e) *Background Counts*
^{3}He is an extremely rare (1.37 ppm) stable isotope. In its production it has to be separated at considerable expense from tritium which, with present day techniques, can be achieved to an extremely high degree (of the order of 1 part of tritium in 10^{13} parts of ^{3}He). This means that the background due to tritium is practically nil and can be readily eliminated by discrimination. Spurious pulses are extremely rare, but care must be taken to keep the connector insulators clean so as to minimise noise arising from electrical breakdown.

Operating Temperature

Use of alumina lead-through seals and high processing temperatures in Centronic ^{3}He counters enables them to be operated at temperatures up to 150°C. The maximum operating temperature may, however, be limited by the connector (when fitted) as indicated on the relevant individual data sheet. If high temperature operation is envisaged, i.e. in excess of 80°C, care should be taken to specify PTFE insulated mating connectors when ordering counters.

Unterminated counters, which are supplied with a flying lead, are available to avoid the temperature restrictions imposed by the connections.

Terminology and Units of Measure

The terminology and units of measure used in this technology can become complex. Where possible, standard units are used and specific abbreviations, such as M for gas multiplication, are defined at the time of use.

The counter output is measured in terms of the rate of output pulses, or counts. This is therefore measured in counts per second, abbreviated to cps.

The characteristic of the neutron field being measured is the density of the neutron flux. This is measured in terms of the number of neutrons crossing an area of 1 square cm per second. Neutron flux density can therefore be defined in terms of $n.cm^{-2}.s^{-1}$ where n is a unitless number meaning 'neutrons'.

Historically, however, neutron flux density has always been considered as the number of neutrons contained within 1 cubic centimetre multiplied by the average neutron speed in centimetres per second. It is designated 'nv'. Whilst the numeric value obtained is the same as in the definition of the above paragraph, the 'n' of 'nv' is not unitless but represents the number of neutrons per cm^3. Velocity is represented by v in $cm.s^{-1.}$

In terms of neutron flux density, therefore, nv is equivalent to $n.cm^{-2}s^{-1}$ because of the different usage of the term 'n'.

Integrated flux over a period of time is normally designated 'nvt', although it's units are neutrons/cm^2.

^{3}He Proportional Counters

The situation becomes more complex when counter sensitivity is considered since this is now a ratio of two rates, or time dependant factors. Sensitivity is designated cps/nv.

Nomenclature of Spherical ^{3}He Counters

The description commences SP to indicate a spherical device, followed by a number which indicates the construction type. He3 indicates ^{3}He as the principle filling gas, followed by a number denoting the filling pressure, in centimetres of mercury. The final letter/number sequence indicates the quench gas used (typically Kr for Krypton or CO2 for carbon dioxide.

Example: SP9He3/304/Kr

SP	-	Spherical construction
9	-	Construction type
He3	-	Gas filling
304	-	Filling pressure (cm of mercury)
Kr	-	Quench gas

Nomenclature of Tubular ^{3}He Counters

The first number denotes the active length in centimetres. This is followed by He3 which indicates ^{3}He as the principle filling gas to which a small quantity of quench gas is added. The next number denotes the gas pressure in centimetres of mercury followed by the approximate cathode diameter in mm. The final letter indicates the latest design standard.

Example: 31He3/304/25E

31	-	Active length (cm)
He3	-	Gas filling
304	-	Filling pressure (cm of mercury)
25	-	Cathode diameter (mm)
E	-	Construction Type

A small quantity of krypton is usually added as a quench gas. If a different quench gas (usually carbon dioxide) is required then this should be specified in addition to the above nomenclature.