Helium-3 Neutron Proportional Counters

Applications

Helium-3 Neutron Detectors are largely sensitive to thermal neutrons and are typically used with a neutron moderator. For this reason, He-3 Proportional Counters are well suited for measuring substrates high in hydrogen, such as water and oil, where the substrate being measured acts as the moderator. In fact, TGM's He-3 detectors are widely used in combination with a fast neutron source to measure the moisture content in soil and in concrete. They are also used to measure the oil content within the strata of an Oil Well while it is being drilled!

Other applications include Nuclear Material Assay, where multiple He-3 Detectors are used in a coincidence circuit to determine the amount of fissionable material. Such devices are used to monitor the enrichment process of nuclear fuel fabrication or to determine an unknown amount of fissionable material suspended in a substrate. Nuclear Material Assay devices are also used in Safeguard applications – verifying the world's inventory of fissionable material.

Theory of Detection

Helium-3 Proportional Counters utilize the He^3 (n,p) H^3 reaction for the detection of thermal neutrons.

$$He^3 + n^1 \text{ (thermal)} \rightarrow H^1 + H^3 + Q$$

where Q = 764KeV.

The energy of the reaction is carried away as kinetic energy of the daughter products, which move in opposite directions.

He-3 Neutron Detectors provide an output pulse which is proportional to 764KeV for thermal neutrons. The cross section of He-3 for thermal neutrons is 5330 barns. The cross section follows a 1/v relationship (v = neutron velocity) up to about 0.2 MeV.

The ionization potential of helium is approximately 25eV; this means that a gas multiplication of about 20 yields a charge per pulse of the order of 0.1 pico coulomb (assuming that all the energy of the He-3 daughter products are deposited within the gas volume). If one increases the voltage on the tube, the gas multiplication will increase, however in an extreme case lifetime will be decreased. A gas gain of 20 is a compromise, it provides a convenient pulse size to work with at the optimum energy resolution without sacrificing lifetime. TGM has developed He-3 Detectors without the use of polyatomic quench gas for exceptional long life.*

** "Design of He-3 Neutron Detectors without the use of polyatomic quench gases" paper presented at IEEE '94 Nuclear Science Symposium.*

Energy Peak and Wall Effect

Only a single full energy peak will be observed for neutron energies that are small compared with 764KeV. On the left of the full energy peak there is a region known as the "wall effect" which contains two discontinuous steps (see figure 7).

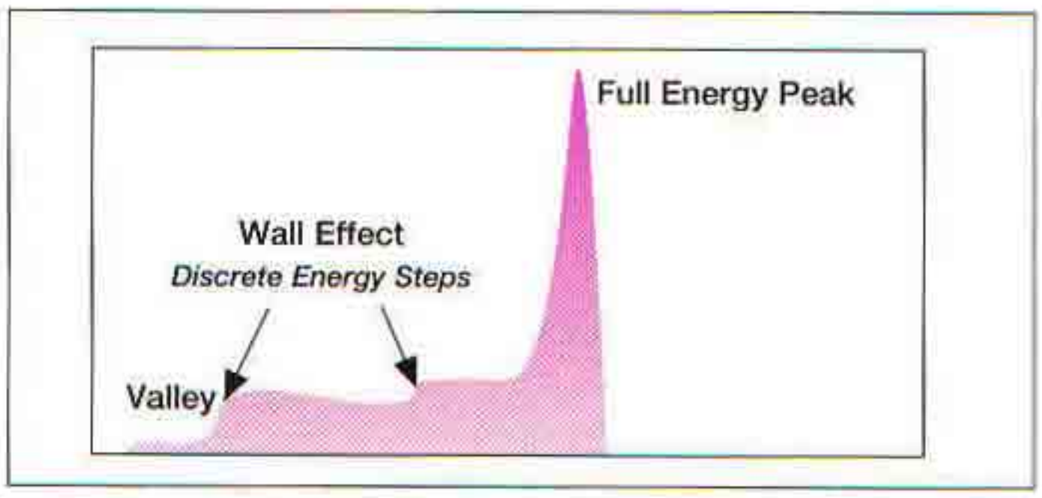


Figure 7 Helium-3 neutron spectrum as viewed on a Multichannel Analyzer.

The wall effect arises because the proton and triton daughter products of the reaction have discrete energies (573KeV and 191KeV respectively) and their ranges in the detector are usually larger than the dimensions of the detector. When one of the daughter products collides with the wall of the detector, its energy is dissipated and does not contribute to the full energy peak, thus creating the discrete steps in the spectrum (see figure 7).

In some cases it is desirable to reduce the wall effect. This can be accomplished in three ways:

(1) Increase the diameter of the detector such that the ratio of daughter products colliding with the wall as compared to events that have the full energy deposited in the gas volume are reduced.

(2) Increase the gas pressure to reduce the range of the daughter products in the gas volume.

(3) Include an amount of a heavier gas in the admixture to increase the stopping power of the gas.

If the size and fill pressure are fixed by other considerations (e.g. sensitivity), the addition of a heavier gas is the common alternative. (*Please note*, adding a heavier gas will increase the gamma sensitivity of the detector.)

Helium-3 Sensitivity

The sensitivity of a He-3 Detector to thermal neutrons is a function of the amount of He-3 gas and increases with gas pressure for a fixed volume. Figures 8 and 9 are graphs of sensitivity per centimeter (cm) active length for different detector diameters at various pressures. To determine sensitivity, multiply the sensitivity per cm for a particular tube diameter by the active length in cm. Please note that the sensitivities are quoted for a standard gas filling of He-3 and carbon dioxide. If a special gas mixture is used which utilizes a large quantity of another gas (e.g. argon) then the following graph serves as a good approximation if only the amount of He-3 is considered.

Special Applications

For Nuclear Material Assay applications where timing is critical for coincidence measurements, the detector needs to be customized by design and gas filling to give a very fast pulse while maintaining the necessary sensitivity and operating voltage. The time characteristics of the output pulse are governed by the charge collection time within the detector, and are optimized by choosing anode size and gas mixtures to provide the most rapid avalanche propagation and recovery. The important characteristics are defined as follows:

(1) Rise time refers to the leading edge of the pulse without regard to pulse polarity. It is the time interval between the pulse at 10% and 90% of the full amplitude.

(2) Jitter time is the maximum time between the ionizing event in the gas and the formation of the voltage pulse.

Variation of Sensitivity with Fill Pressure

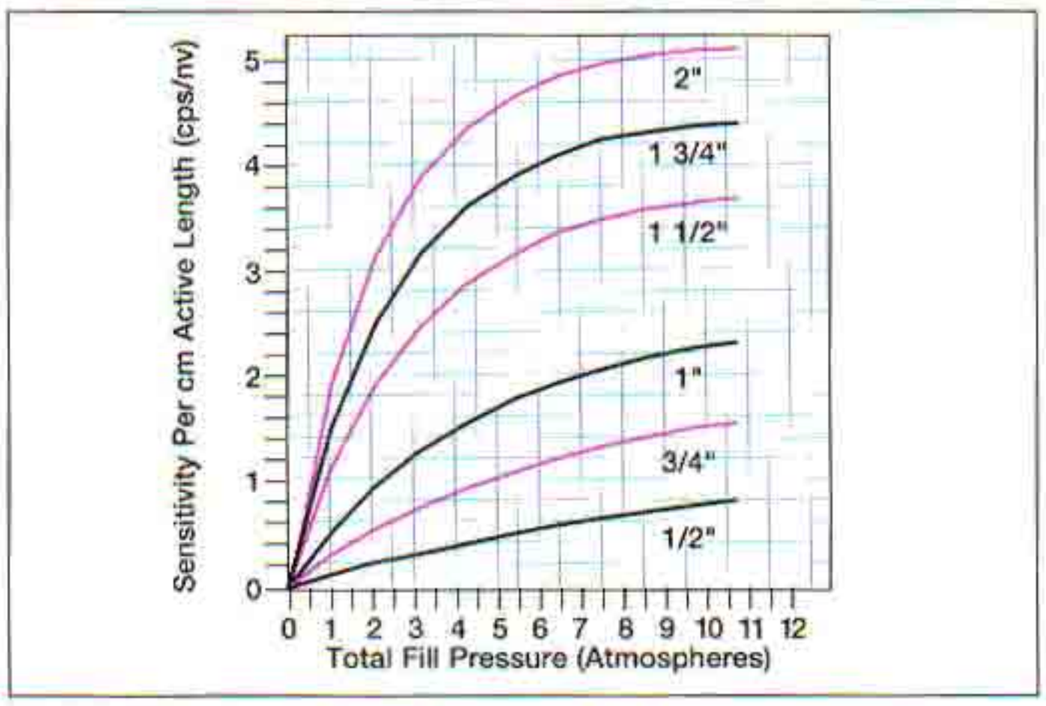


Figure 8 Helium-3 sensitivity per unit length for increasing gas pressure.

For low sensitivity applications figure 9 is a graph of sensitivity per cm active length for fill pressures 1-2 atmospheres.

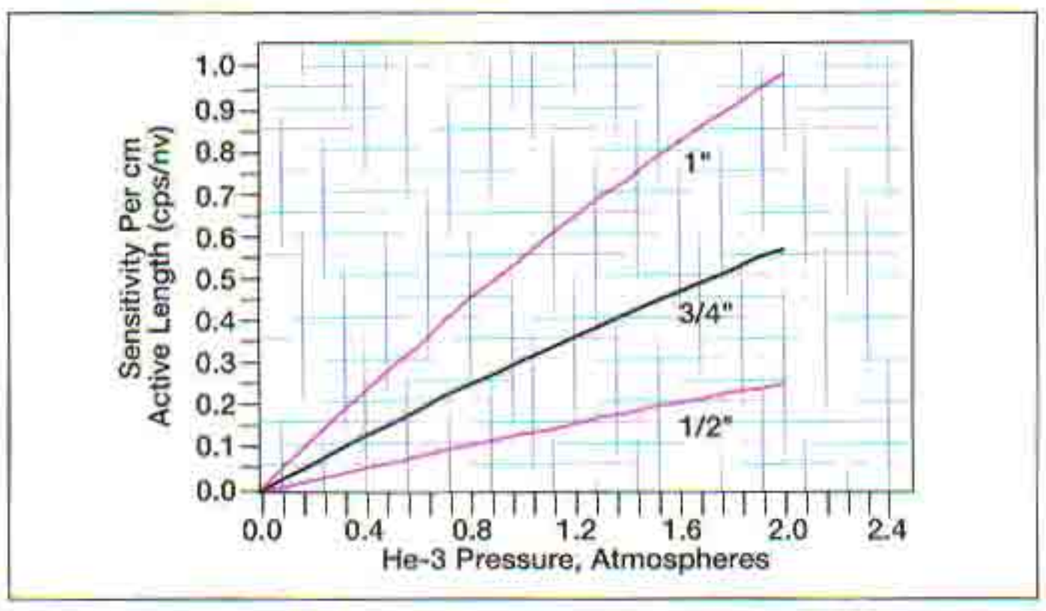


Figure 9 Helium-3 sensitivity per unit length for low gas pressures

BF3 Neutron Proportional Counters

Applications

Like Helium-3, Boron Tri-fluoride (BF_3) Proportional Counters are largely sensitive to Thermal Neutrons. Typical applications include: Thermal Neutron Diffraction, Spectroscopy, Industrial Gauging and Neutron Monitoring. Because TGM's BF_3 Proportional Counters can be used in gamma fields up to 100 R/h, they are well suited for measuring neutrons in mixed waste.

Theory of Detection

BF_3 neutron Proportional Counters utilize the B^{10}(n,alpha) Li^7 reaction.

$$B^{10} + n^1 \rightarrow Li^7 + \text{alpha} + Q$$

In 93% of the reactions Q = 2.31 MeV, leaving the Lithium nuclide in the first excited state. The other 7% of the reactions have Q = 2.79 MeV, with the Lithium nuclide in the ground state.

The energy from the reaction with a thermal neutron is shared as kinetic energy of the daughter products. The reaction products are 0.84 MeV and 1.47 MeV for the Lithium nuclide and alpha particle respectively.

BF3 compared to He-3 Neutron Detectors

BF_3 neutron detectors contain boron enriched to >90% B^{10}. The thermal neutron cross section for B^{10} is 3840 barns. This is considerably less than the cross section of He-3 for thermal neutrons. The cross section drops off as 1/v up to about 0.1 MeV (v = neutron velocity).

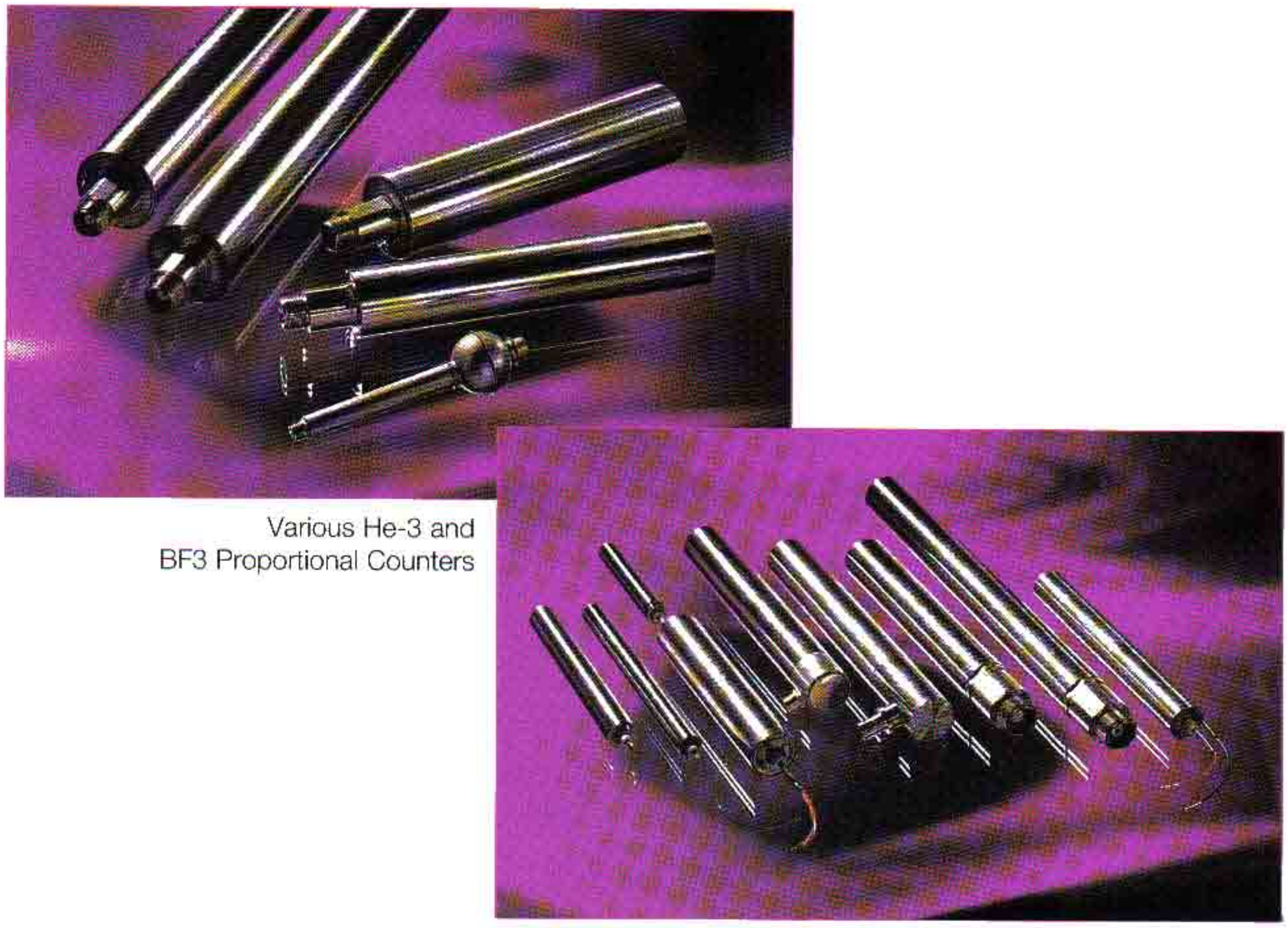
Compared to He^3, B^{10} has a lower cross section for thermal neutrons, making BF_3 detectors less sensitive. The one advantage is that the Q of the neutron reaction is much larger than for He-3, making it is easier to discriminate against gamma pulses with a BF_3 tube. BF_3 detectors can easily be used in gamma fluxes of 100 R/hr and will give a life in excess of 10^{17} n/cm^2 (lifetime defined as a 10% reduction in original sensitivity).

Compared to He-3, BF_3 detectors function at much higher operating voltages. If more than 2-2.5 KV is necessary, it is recommended that a guard ring be used on the anode insulator. Guard rings prevent electrical leakage across the insulator contributing to the noise level of the signal from the detector.

Helium-3 Neutron Proportional Counters

TGM Part Number	Length		He-3 Gas Pressure, Sensitivity and Operating Voltage				
			2 ATM (xxx = 152)	4 ATM (xxx = 304)	6 ATM (xxx = 456)	8 ATM (xxx = 608)	10 ATM (xxx = 760)
Replace the xxx in each part number with the number specified under He-3 Gas Pressure	ACTIVE	OVERALL	Operating Dia. Voltage 0.5 = 750 0.75 = 800 1.0 = 850 1.5 = 1000 2.0 = 1100	Operating Dia. Voltage 0.5 = 950 0.75 = 1000 1.0 = 1100 1.5 = 1400 2.0 = 1500	Operating Dia. Voltage 0.5 = 1150 0.75 = 1200 1.0 = 1350 1.5 = 1500 2.0 = —	Operating Dia. Voltage 0.5 = 1350 0.75 = 1400 1.0 = 1450 1.5 = 1600 2.0 = —	Operating Dia. Voltage 0.5 = 1650 0.75 = 1700 1.0 = 1750 1.5 = 1850 2.0 = —
0.5" Dia. Tubes	Inches		cps/nv	cps/nv	cps/nv	cps/nv	cps/nv
7.6He3/xxx/13	3.0	4.4	2.2	3.8	5.1	6.1	6.9
15He3/xxx/13	5.9	7.3	4.3	7.6	10	12	14
25He3/xxx/13	9.8	11.2	7.1	13	17	20	23
50He3/xxx/13	20	21.1	14	25	34	40	46
0.75" Dia. Tubes	Inches		cps/nv	cps/nv	cps/nv	cps/nv	cps/nv
7.6He3/xxx/19	3.0	4.0	4.6	7.7	9.8	11	12
15He3/xxx/19	5.9	6.9	9.0	15	19	22	24
25He3/xxx/19	9.8	10.8	15	25	32	37	40
50He3/xxx/19	20	19.7	30	51	65	74	81
1" Dia. Tubes	Inches		cps/nv	cps/nv	cps/nv	cps/nv	cps/nv
9.6He3/xxx/25	3.8	5.2	9.7	16	19	21	22
12.7He3/xxx/25	5.0	6.2	13	21	25	28	30
15He3/xxx/25	5.9	7.9	15	24	30	33	35
25He3/xxx/25	9.8	11.8	25	40	50	55	58
50He3/xxx/25	19.7	21.7	50	81	99	110	117
100He3/xxx/25	39.4	41.4	101	161	198	220	234
125He3/xxx/25	49.2	51.2	126	202	248	275	292
1.5" Dia. Tubes	Inches		cps/nv	cps/nv	cps/nv	cps/nv	cps/nv
15He3/xxx/38	5.9	7.9	30	45	51	54	56
25He3/xxx/38	9.8	11.8	51	74	85	91	93
50He3/xxx/38	19.7	21.7	101	149	171	181	186
100He3/xxx/38	39.4	41.4	202	297	342	363	372
1.25" Dia. Spherical	Inches		cps/nv	cps/nv			
SP90[1]	1.3	5.0	3.9	5.9			
2" Dia. Tubes	Inches		cps/nv	cps/nv			
15He3/xxx/50	5.9	7.9	48	66			
25He3/xxx/50	9.8	11.8	81	110			
50He3/xxx/50	19.7	21.7	161	220			
100He3/xxx/50	39.4	41.4	322	441			

All He-3 detectors listed are made of Stainless Steel. 1" and 2" diameter tubes are also available with aluminum construction up to 4 ATM pressure. 1", 1.5" and 2" diameter tubes come standard with HN connectors. Other connectors available upon request. All He-3 detectors are available with activated carbon coating.



Various He-3 and
BF3 Proportional Counters

Boron Trifloride Neutron Proportional Counters

TGM Part Number		BF3 Gas Pressure, Sensitivity and Operating Voltage					
		20 cm Hg (xx = 20)		40 cm Hg (xx = 40)		70 cm Hg (xx = 70)	
Replace the xx in each part number with the number specified under He-3 Gas Pressure	Active Length	Sensitivity	Operating Voltage	Sensitivity	Operating Voltage	Sensitivity	Operating Voltage
1" Dia. Tubes	Inches	cps/nv	Volts	cps/nv	Volts	cps/nv	Volts
12.7BF3/xx/25	5.0	1.5	1000	3.0	1300	5.0	1900
15BF3/xx/25	5.9	1.8	1000	3.5	1300	5.9	1900
25BF3/xx/25	9.8	3.0	1000	5.8	1300	9.8	1900
50BF3/xx/25	19.7	6.0	1000	12	1300	20	1900
100BF3/xx/25	39.4	12	1000	23	1300	39	1900
125BF3/xx/25	49.2	15	1000	29	1300	49	1900
2" Dia. Tubes	Inches	cps/nv	Volts	cps/nv	Volts	cps/nv	Volts
15BF3/xx/50	5.9	70	1200	13	1500	22	2100
25BF3/xx/50	9.8	12	1200	22	1500	36	2100
50BF3/xx/50	19.7	23	1200	44	1500	72	2100
100BF3/xx/50	39.4	46	1200	88	1500	145	2100

All detectors available in S.S., Aluminum or Copper Construction. HN connectors are Standard. Other connectors available.