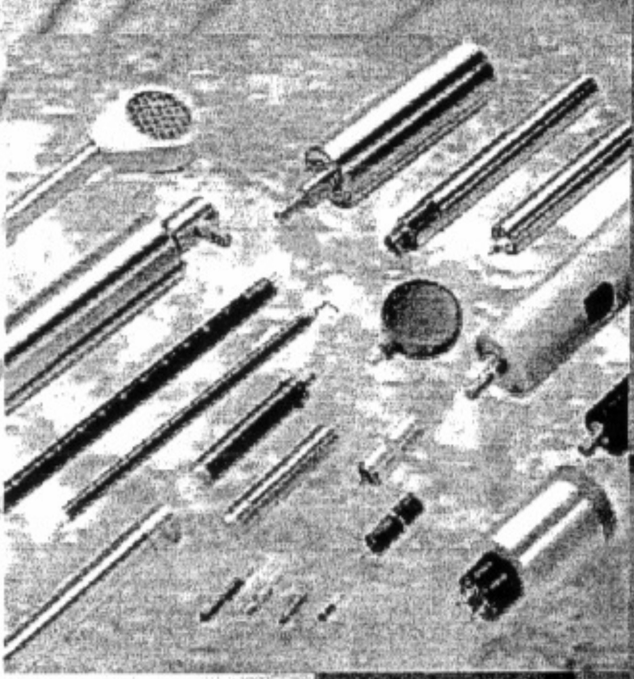
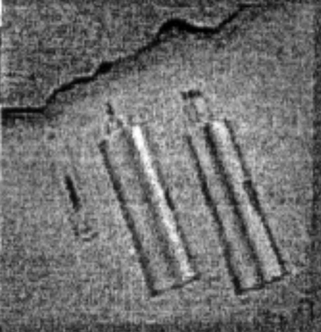
// Novembre 2005 //

Scintillation Products





Gas-filled Radiation Detectors: Proportional Counters

SAINT-GOBAIN
CRYSTALS & DETECTORS

General Theory –

Gas-filled radiation detectors have been used in various forms since the turn of the last century. They are devices which are relatively simple and very reliable, and have proven their worth against the test of time. There are many different types of detectors, however, all types can be organized into three general categories: ionization chambers, proportional counters, and Geiger-Müller (G-M) tubes.

The difference between these three detector categories is illustrated by considering a detector, which consists of a wire anode within a cylindrical cathode. If the detector is subject to a constant radiation field, the size of the output pulse will be a function of applied voltage, as shown in Figure 1.

Incident radiation causes ionization in the gas, which creates positive ions and electrons (ion pairs) within the gas volume. With no applied voltages, the ion pairs recombine to form neutral gas molecules. As voltage is applied between anode and cathode, the electric field causes electrons to be swept toward the anode and positive ions toward the cathode.

The output current provides a measure of the number of ion pairs created and, therefore, the amount of incident radiation; this is the ionization region.

If the applied voltage is increased, electrons traveling toward the anode acquire enough kinetic energy to further ionize the gas by collision. This cascading electron multiplication amplifies the output signal of the detector. This is the region in which proportional counters operate. The size of the output pulse is proportional to the number of initial ion pairs, which provides a measure of the incident radiation energy.

As the voltage is further increased, the detector will enter the Geiger region. In this region the detector will provide the maximum output pulse, independent of the number of ions formed from the incident radiation event. Therefore, any information as to energy of the incident radiation is lost.

General Information
Gas-filled Radiation Detectors

Our corporate objective is to take a proven technology forward to exceed tomorrow's standards. We have successfully accomplished this for many industries. Helium-3 neutron detectors have been developed that will withstand the high vibration, high temperature environments of today's "Measurement While Drilling" Oil Well Logging applications. Furthermore, the standard for X-Ray proportional counter resolution continues to be elevated. Due to accomplishments such as these, gas-filled detectors remain one of the most popular technologies in radiation detection and SGCD continues to be an industry leader.

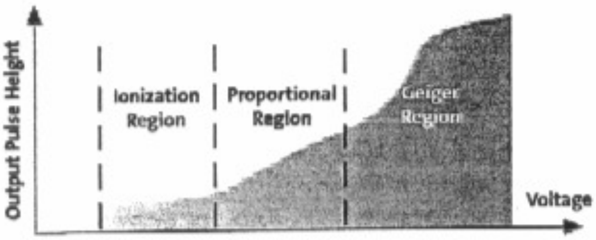
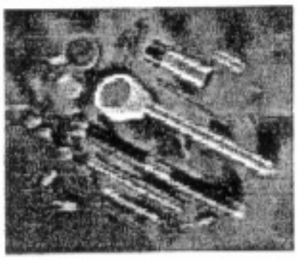
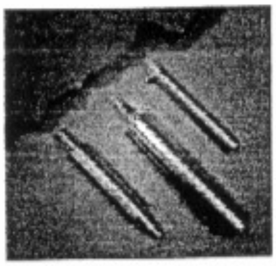


Figure 1 Plot of detector output vs. applied voltage for gas-filled radiation detectors

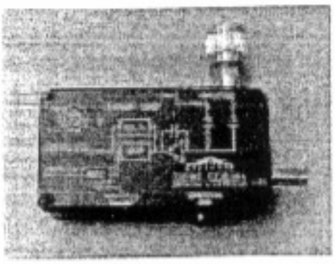
G-M tubes and probes provide effective means for detecting and measuring alpha and beta particles, gamma rays and X-rays. Specific G-M product information is available in a separate brochure.





Common styles of proportional counters are shown and listed in this brochure; however, modifications such as length and sensitivity are easily accommodated.

The CHAMP 100, 200, and 300 charge amplifiers are sensitive, low noise devices which make them ideal for critical applications. They can be used with He-3 neutron detectors, X-ray tubes and other proportional counters.



General Description
Proportional Counters

SGCD manufactures many different types of proportional counters. There are several standard types; however, most tubes are custom built for specific applications. The detectors manufactured by SGCD can be classified into two broad categories: X-Ray proportional counters, and Helium-3 proportional counters. Within each category, there is a wide variety of designs and configurations – this catalog contains some of the most common models. Expert technical support is available to help select or design a detector for a specific application.

Proportional counters consist of an anode (or anodes) and a cathode with a gas filling contained in a hermetically sealed envelope. The most common configuration is that of a cylindrical cathode (also acting as the hermetic container) enclosing a volume with a wire anode in the center of the detector. Other configurations are possible; for example, a flat detector with one or multiple anodes is often used in detectors built for surveying surfaces. For extremely thin windows (to maximize alpha and beta particle sensitivities), flow counters are commonly used. For these types of detectors, the gas volume is not sealed and the counting gas is slowly flowed through the active volume of the detector. Proportional counter output provides information as to the energy and amount of incident radiation. For some applications, it is desirable to know the point at which the radiation enters the detector. Proportional counters can be built with special anodes or anode arrays to yield this additional information (position sensitive detectors).

Proportional counters are high voltage devices, most requiring between 1000 and 2000 volts to operate; however, they require little power, so low current (approximately 1 mA) power supplies can be used. A preamplifier is necessary to decouple the signal from the detector. Normally, a charge sensitive preamplifier is used. SGCD offers the CHAMP100, 200 and 300 model preamplifiers for low noise, high performance applications.

Typical Counting Circuits –

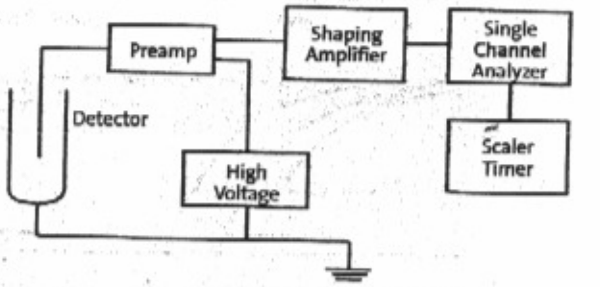


Figure 2a Typical General Counting Circuit

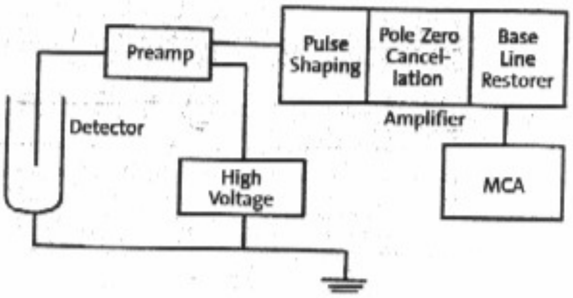


Figure 2b Typical Circuit for Spectroscopy Applications

Theory of Operation –

Incident radiation interacts with the detector's gas filling, creating ion pairs. Electrons are accelerated toward the anode under the influence of an electric field. As electrons move toward the anode, they collide with neutral gas molecules. Some of these collisions will have sufficient energy to create more ion pairs. The secondary electron generation from collision amplifies the electron signal at the anode, which leads to a larger output pulse. A proportional counter is operated so that the output pulse size is proportional to the initial number of ion pairs. The number of output pulses provides information as to the amount of incident radiation, and the size of the pulses provides information as to the energy of the incident radiation.

Gas Gain –

The ratio of the charge collected at the anode compared to the charge from the initial ion pair creation is called gas gain or multiplication. For proportional counters, the operating voltage is adjusted to obtain the desired gas gain.

Resolution and Noise –

An important characteristic of proportional counters is the resolution of the full energy peak, usually measured on a multichannel analyzer. In an ideal case, pulses caused by monoenergetic radiation would all be the same height, and the multichannel analyzer would display a single line that would represent the radiation energy. In practice, a peak with a measurable width is observed. There are several contributing factors to the width of the energy peak, including statistical variations, detector geometry, gas purity and electronic noise. The statistical variations set a maximum possible resolution for a given geometry.

The electronic noise contribution can be limited by careful selection of electronic components and by limiting stray capacitance. It is desirable to keep the distance between the detector and the preamplifier as short as possible. The detector and electronics should be shielded from electrical interference and well grounded in order to exclude extraneous noise from the counting system. Care should be taken when handling detectors and electronics to avoid noise due to contamination.

Microphonics –

Proportional counters have very small diameter anode wires. Exposure to high vibration environments may produce spurious pulses due to relative movement between the anode and cathode. This effect is known as microphonics. SGCD has developed proprietary ruggedizing techniques to produce ruggedized detectors with minimal microphonic response.

X-ray Proportional Counters

X-ray proportional counters are ideal detectors for low energy X-ray measurement. They can provide optimal performance and high resolution in applications such as: X-ray fluorescence spectroscopy, thin film thickness gauging, and Mossbauer spectroscopy.

Theory of Detection –

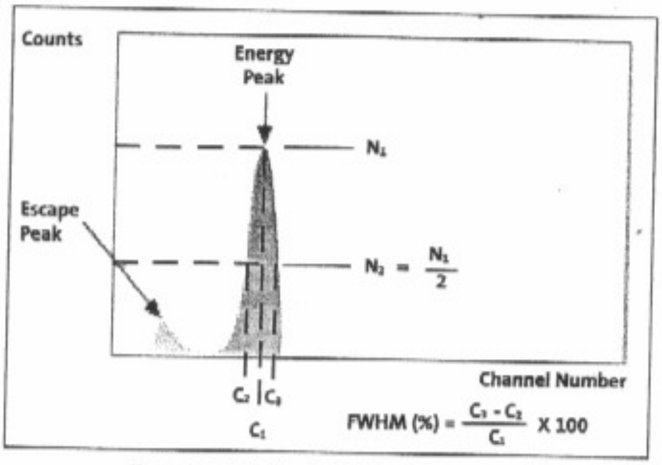
The counting gas used in X-ray proportional counters is normally a mixture of a noble gas and a small amount of a polyatomic quench gas. The detector uses photoelectric absorption as the detection mechanism. When an X-ray photon enters the gas volume, it is completely absorbed by a gas atom, which then ejects an energetic photoelectron from a bound energy shell. The energy of the photoelectron is the difference between the energy of the incident photon and the energy of the bound state of the electron. The output pulse from the detector will be proportional to the energy of the photoelectron; this is directly related to the energy of the incident photon. A pulse height measuring system can therefore be used to provide information about the incident photon energy.

In most cases, the photoelectron is ejected from the tightest bound energy level, the K energy shell. The positive ion that is created will capture a free electron with a possible rearrangement of the electron energy shells, this leads to the emission of a characteristic X-ray that is reabsorbed in the gas volume. The characteristic K alpha energies for Neon, Argon, and Xenon are 0.85, 2.97 and 29.7 keV respectively. These characteristic X-rays may lead to an "escape peak" at the corresponding energy below the full energy peak (see Figure 3). This can be avoided by choosing a gas with a characteristic X-Ray of higher energy than the incident radiation.

Detector Efficiency –

The efficiency of a detector is the product of window transmission and gas absorption for a specific X-ray energy. Figure 4 is a plot of window transmission vs. photon energy for Beryllium, and Figures 5 a, b, c and d are the absorption curves for Ne, Ar, Kr and Xe. Absorption of X-rays varies directly with the atomic number (Z) of the absorber material. Choice of materials, including the detector gas, is critical.

The detector body materials should be low Z, which is why aluminum counter bodies with beryllium windows are common. The gas should be chosen based upon which X-ray energies are to be observed.



$$\text{FWHM (\%)} = \frac{C_3 - C_2}{C_1} \times 100$$

Figure 3 Calculating FWHM Energy Resolution using a Multichannel Analyzer

Resolution –

The energy resolution of an X-ray proportional counter is normally defined as the "Full Width Half Max" (FWHM) resolution for the full energy peak. Using a multichannel analyzer, one can determine the FWHM resolution by using the equation referred to in Figure 3. N_1 is the total number of counts in peak channel number C_1. N_2 is defined as N_1 divided by 2 and may be located on both sides of the energy peak in channel numbers C_2 and C_3.

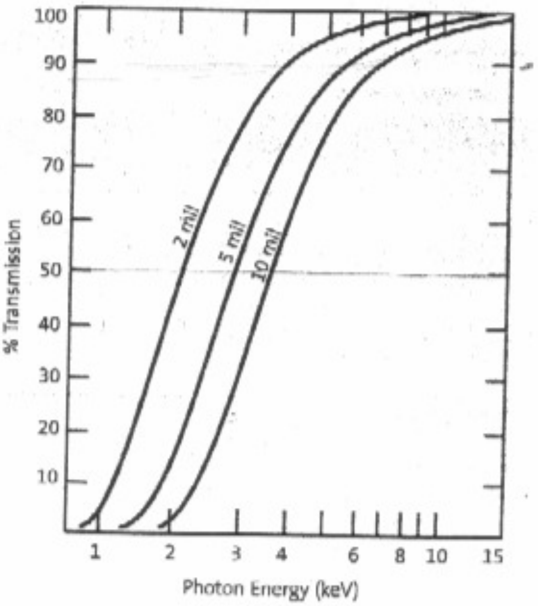


Figure 4 Beryllium Transmission at Various Photon Energies

X-ray Proportional Counters

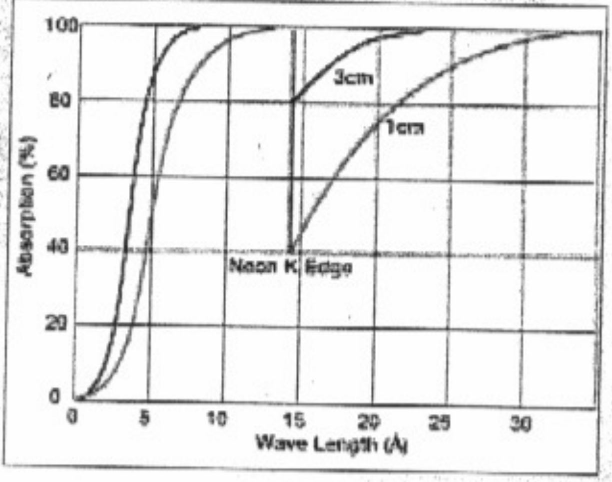


Figure 5a Absorption of Neon at 1 atm.

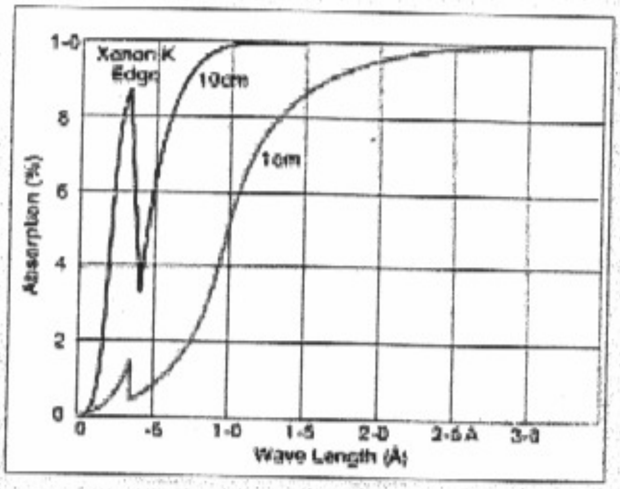


Figure 5b Absorption of Xenon at 1 atm.

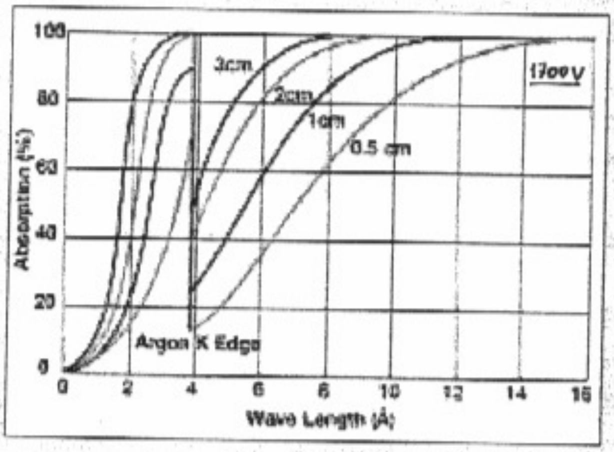


Figure 5c Absorption of Argon at 1 atm.

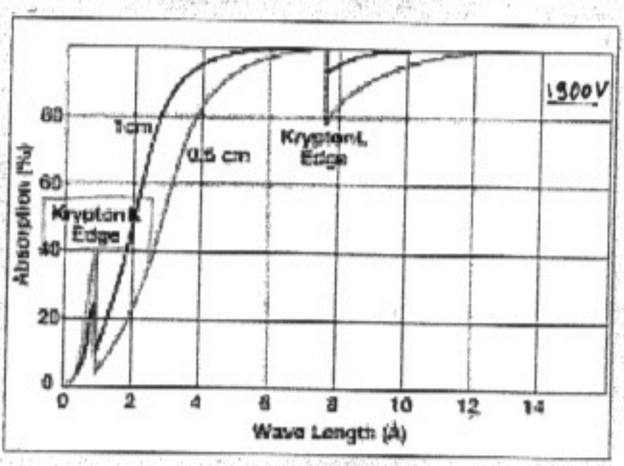
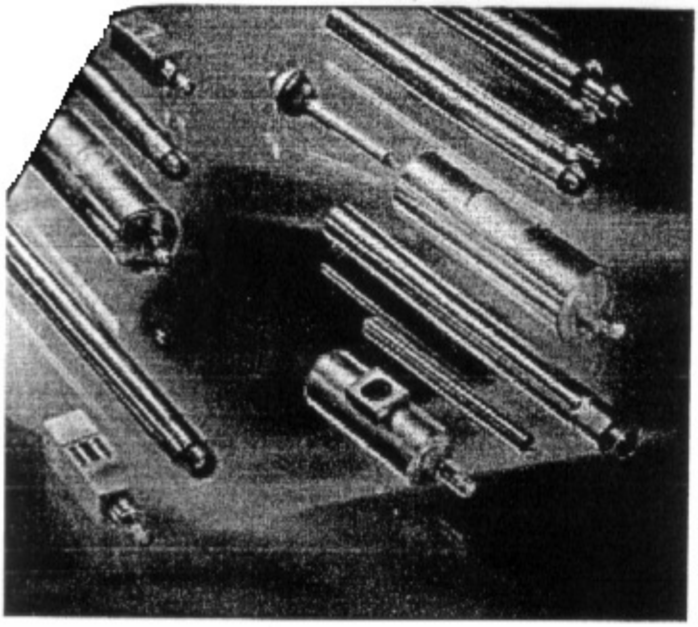


Figure 5d Absorption of Neon at 1 atm.

Kr



X-ray Proportional Counters

Gas: Ar, Xe 1 atm

Quench gas: 3% CO_2

Diametro filo anodo: 50.8 μm

X-Ray Proportional Counter Configuration Examples –

	SGCD Part Number	Overall Outside Diameter	Overall Length[1]	Body Material	Window Dimensions	Window Material[2]
	X-Ray Counters	**Inches**	**Inches**		**Inches**	
Z	TPX201/Ne	2.0	5.9	Aluminum	1" Diameter	Al or Be
18 X→	TPX201/Ar	2.0	5.9	Aluminum	1" Diameter	Al or Be 10 mil
54 X→	TPX201/Xe	2.0	5.9	Aluminum	1" Diameter	Al or Be 10 mil
	TPX301/Ne	1.0" Square	3.0	Aluminum	0.75" Diameter	Al or Be
	TPX301/Ar	1.0" Square	3.0	Aluminum	0.75" Diameter	Al or Be
	TPX301/Xe	1.0" Square	3.0	Aluminum	0.75" Diameter	Al or Be
	TPX501/Ne	2.0	6.9	Aluminum	1 x 2" Oval	Al or Be
	TPX501/Ar	2.0	6.9	Aluminum	1 x 2" Oval	Al or Be
	TPX501/Xe	2.0	6.9	Aluminum	1 x 2" Oval	Al or Be
	TPX601/Ne	1.5	3.8	Aluminum	0.75" Diameter	Al or Be
	TPX601/Ar	1.5	3.8	Aluminum	0.75" Diameter	Al or Be
	TPX601/Xe	1.5	3.8	Aluminum	0.75" Diameter	Al or Be
	TPX111/Ne	1.0	3.7	S.S. or Al	0.38 x 1" Oval	Al or Be
	TPX111/Ar	1.0	3.7	S.S. or Al	0.38 x 1" Oval	Al or Be
	TPX111/Xe	1.0	3.7	S.S. or Al	0.38 x 1" Oval	Al or Be
	Large Area	**Inches**	**Inches**		**Inches**	**mg/cm2**
	TPF101[4]	4.0	see note 4	Copper	2" Diameter	Mylar - 0.8
	TPF301[3]	4.7 x 8.3 x 0.7	8.3	Aluminum	4.0 x 6.4"	Mylar - 0.8
	TPA301/Ar[5]	4.7 x 8.3 x 0.7	8.3	Aluminum	4.0 x 6.4"	Aluminum - 3.0
	TPA301/Xe[5]	4.7 x 8.3 x 0.7	8.3	Aluminum	4.0 x 6.4"	Aluminum - 5.0

1) Overall length does not include cable connector.

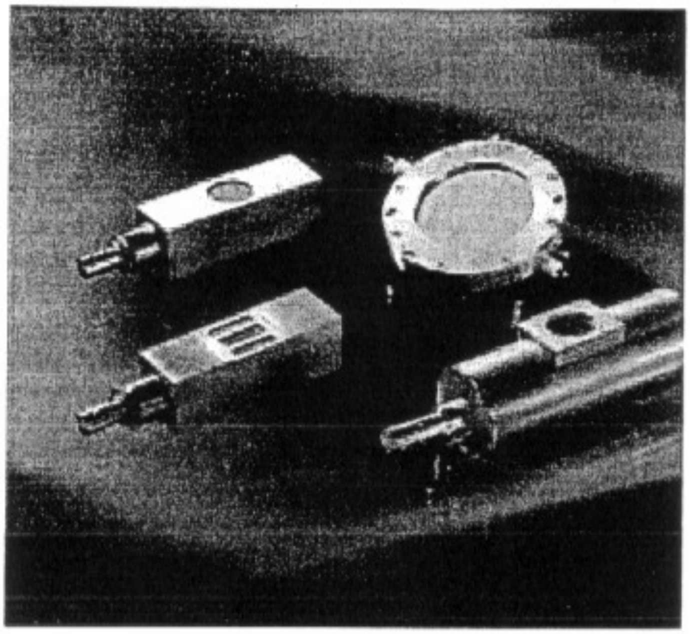
2) Aluminum and beryllium windows are available at 0.002, 0.005 or 0.010 inches thickness.

3) Low background, gas flow proportional counter used for alpha, beta, gamma detection.

4) Pancake style.

5) 100 cm² open window area.

6) Available with 2 atm. pressure.



	Gas/Pressure	Optimal Energy Range	Fe-55* FWHM Resolution	Am-241* FWHM Resolution	Típico Operating* Voltage	Connector
	Atmospheres*	**keV**	**Percent**	**Percent**	**Volts**	**Coaxial Cable**
Z	Neon / 1 atm.	1 to 5	< 18	—	1500	MHV, SHV
18 →	Argon / 1 atm.	5 to 15	< 18	—	1700	MHV, SHV
54 →	Xenon / 1 atm.	10 to 50	18 - 20	9 - 12	1900	MHV, SHV
	Neon / 1 atm.	1 to 5	< 18	—	1300	MHV, SHV
	Argon / 1 atm.	5 to 15	< 18	—	1500	MHV, SHV
	Xenon / 1 atm.	10 to 50	18 - 20	8 - 11	1700	MHV, SHV
	Neon / 1 atm.	1 to 5	< 18	—	1500	MHV, SHV
	Argon / 1 atm.	5 to 15	< 18	—	1700	MHV, SHV
	Xenon / 1 atm.	10 to 50	18 - 20	9 - 12	1900	MHV, SHV
	Neon / 1 atm.	1 to 5	< 18	—	1400	MHV, SHV
	Argon / 1 atm.	5 to 15	< 18	—	1600	MHV, SHV
	Xenon / 1 atm.	10 to 50	< 18	8 - 11	1800	MHV, SHV
	Neon / 1 atm.	1 to 5	< 18	—	1300	MHV, SHV
	Argon / 1 atm.	5 to 15	< 18	—	1500	MHV, SHV
	Xenon / 1 atm.	10 to 50	< 18	8 - 11	1700	MHV, SHV
	Atmospheres	**Radiation**	**Percent**	**Percent**	**Volts**	**Coaxial Cable**
	P10 / Gas Flow	α,β,γ*	< 18	—	1500	—
	P10 / Gas Flow	α,β,γ	< 18	—	1500	MHV, SHV
	Argon / 1 atm.	α,β,γ	< 16	—	1200	MHV, SHV
	Xenon / 1 atm.	β,γ	< 18	—	1400	MHV, SHV

*Note: Specifications are nominal and may differ with customer electronics.

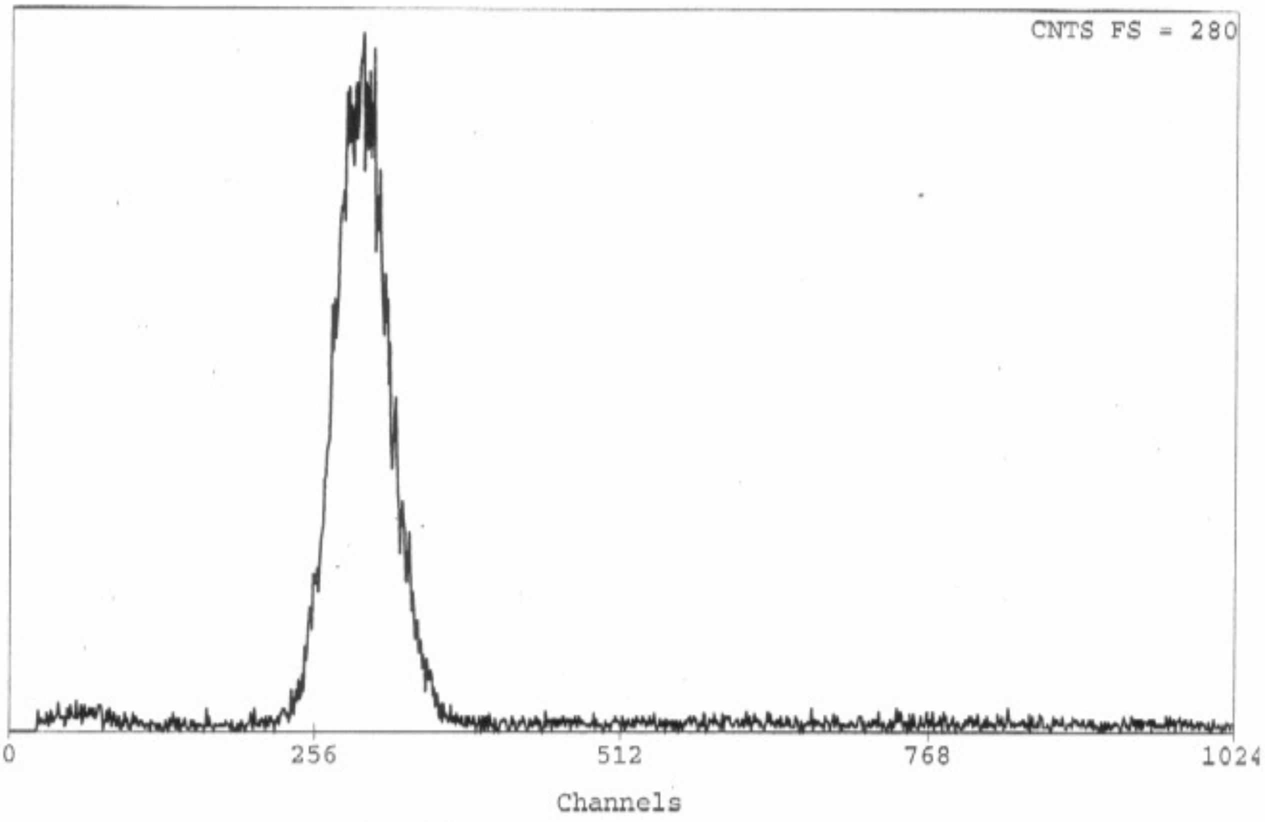
CONTATORE PROPORZIONALE

Saint-Gobain Crystals

Friday, February 03, 2006

^{55}Fe

```
ID(1): SG#F0154       TPX201-10Xe      2200V     Preship   (Ortec142,5,20:50:2)
File:                    Date: 03-Feb-06 13:54:04LT: 29.68           RT: 30.00
Bias: 0                  Coarse Gain: 0          Coarse Gain: 0.00
```



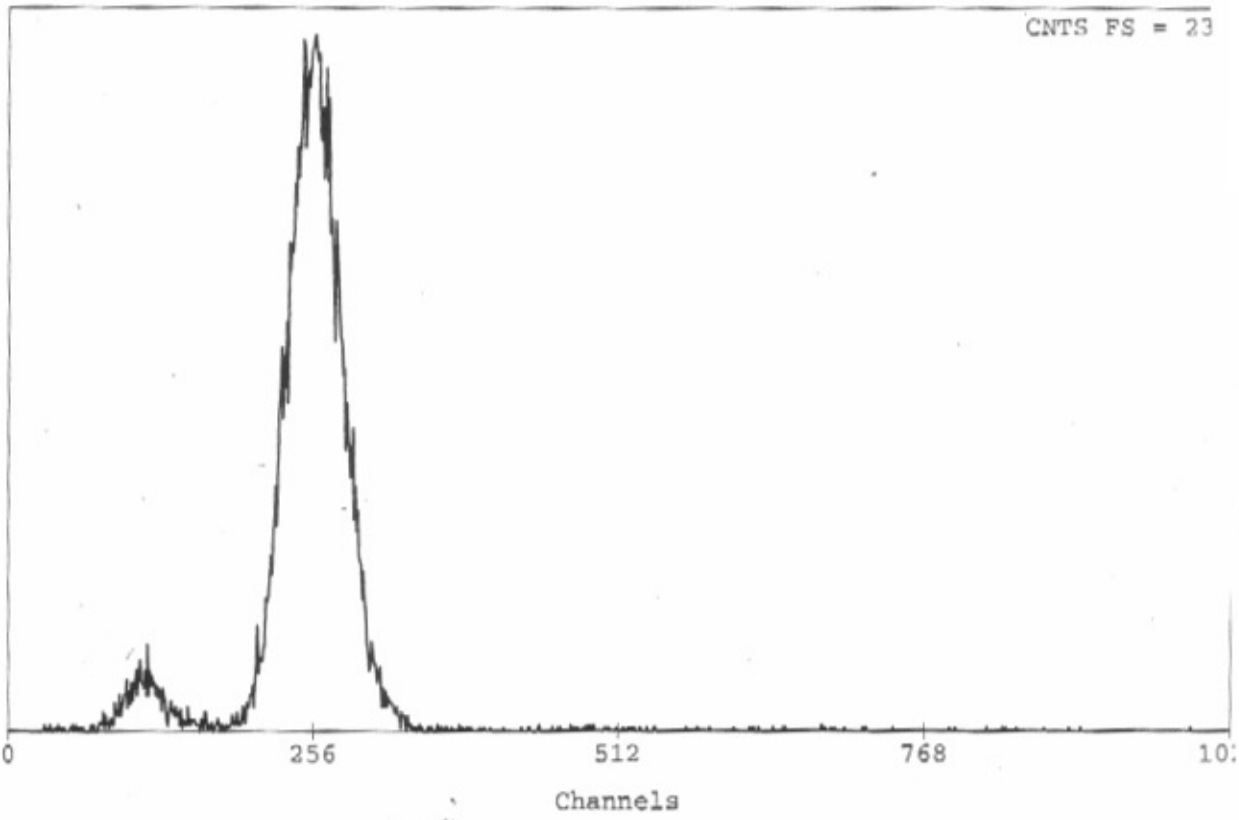
ROI #	ID	ASSOCIATED NUCLIDE	Cmax CENTER ? (keV)	GROSS (cnts)	NET (cnts)	Δc FWHM (keV)	FWHM (%)
1	ROI # 1		292.6	17,312 ± 132	15,270 ± 1,029	47.88	16.37

Saint-Gobain Crystals

Friday, February 03, 2006

^{55}Fe

ID(1): SG#F0151 TPX201-10Ar 1800V Preship (Ortec142,5,20:50:2)
File: Date: 03-Feb-06 13:58:34LT: 29.84 RT: 30.00
Bias: 0 Coarse Gain: 0 Coarse Gain: 0.00



channel

ROI #	ID	ASSOCIATED NUCLIDE	CENTER ? (keV)	GROSS (cnts)	NET (cnts)	FWHM (keV)	FWHM (%)
1	ROI # 1		255.3	13,074 ± 114	13,074 ± 114	47.05	18.43

Helium-3 Neutron Proportional Counters

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. Our 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; in Nuclear Material Assay, where multiple He-3 detectors are used in a coincidence circuit to determine the amount of fissionable material. Nuclear Material Assay devices are also used in safeguard applications – verifying the world's inventory of fissionable material.

Energy Peak and Wall Effect –

Only a single full energy peak will be observed for neutron energies that are small compared with 764 keV. On the left of the full energy peak, there is a region known as the "wall effect" which contains two discontinuous steps (see Figure 6).

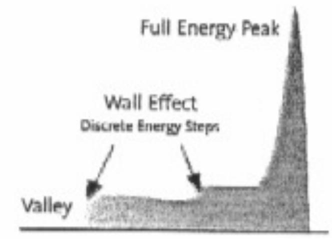


Figure 6 Helium-3 neutron spectrum as viewed on a Multichannel Analyzer

The wall effect arises because the proton and triton daughter products of the reaction have discrete energies (573 keV and 191 keV 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 6).

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.)

Variation of Sensitivity with Fill Pressure –

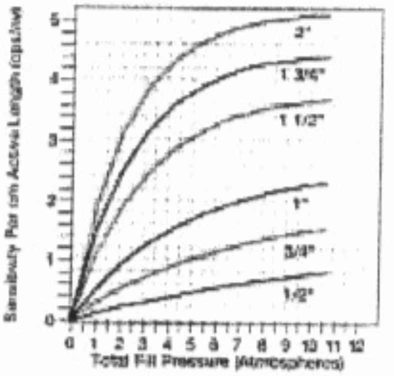


Figure 7 Helium-3 sensitivity per unit length for increasing gas pressure

For low sensitivity applications, Figure 8 is a graph of sensitivity per cm active length for fill pressures 1-2 atmospheres.

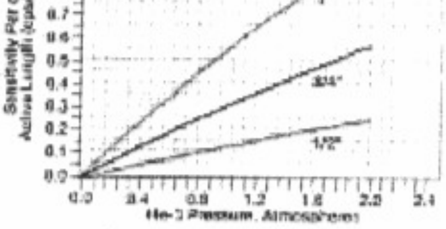


Figure 8 Helium-3 sensitivity per unit length for low gas pressure

Theory of Detection –

Helium 3 proportional counters utilize the He (n, p) H reaction for the detection of thermal neutrons.

$^3He + ^1n$ (thermal) => $^1H + ^3T + Q$

Where Q = 764 keV.

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 that is proportional to 764 keV 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, if excessive voltage is applied, 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.

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 7 and 8 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.

Helium-3 Neutron Proportional Counters

He-3 Neutron Proportional Counters Configuration Examples –

SGCD 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	Dia. Operating Voltage 0.5 = 750 0.75 = 800 1.0 = 850 1.5 = 1000 2.0 = 1100	Dia. Operating Voltage 0.5 = 950 0.75 = 1000 1.0 = 1100 1.5 - 1400 2.0 = 1500	Dia. Operating Voltage 0.5 = 1150 0.75 = 1200 1.0 = 1350 1.5 = 1500 2.0 - –	Dia. Operating Voltage 0.5 = 1350 0.75 = 1400 1.0 = 1450 1.5 - 1600 2.0 = –	Dia. Operating 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	1.3	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.