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OPERATION OF ^{3}He PROPORTIONAL CHAMBERS IN HIGH GAMMA RADIATION FIELDS

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ABSTRACT

Operation of ^{3}He proportional chambers with irradiated fissile materials is limited because of the sensitivity of these chambers to gamma ray events. The optimum performance of these chambers is achieved with proper selection of an additive gas to the chambers and with proper choice of preamplifier and linear amplifier time constants. The counting efficiency of a 4-atm, ^{3}He-CO_2 chamber is improved from 35% to 43% in a 200 R/hr gamma radiation field by decreasing the linear amplifier time constant. Likewise, the counting efficiency of a 1-atm, ^{3}He-CF_4 is improved from 11% to 14% in a 200 R/hr gamma radiation field by decreasing the linear amplifier time constant. The 4-atm, ^{3}He-CO_2 1-in.-OD chamber has a higher efficiency than the 1-atm, ^{3}He-CF_4 1-in.-OD chamber although the energy resolution of the ^{3}He-CF_4 chamber is better than that for the ^{3}He-CO_2 chamber.

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I. INTRODUCTION

^{3}He proportional counters are high-efficiency thermal neutron detectors that have numerous applications in measurements with fissile materials. However, one disadvantage of these chambers is their sensitivity to gamma rays which essentially limits the application of these detectors to measurements with unirradiated nuclear fuels. Gamma ray interactions with the chamber walls result in the emission of electrons that produce ionization in the gas. As the gamma-radiation field intensity increases, the number of pulses due to electron interactions increases and can pile up. Consequently, in high gamma ray fields, gamma ray pile up becomes the major contributor to the detector response. The magnitude of the effect of gamma ray pile up depends on the quench-gas, the preamplifier time constants, and the amplifier time constants.

In proportional counters, quench gases are typically added to the primary gas to suppress photon-induced events and to increase the electron drift velocity in the gas [1,2]. Increasing the electron drift velocity reduces pulse rise time to allow the chamber to operate at higher count rates. Kopp, et. al. [3] investigated the use of varying gas mixtures for ^{3}He chambers and indicated that a ^3He-CF_4 gas mixture had a larger electron drift velocity than ^3He-Xe-CO_2 for the same operating voltage and gas pressure. Measurements performed by Koehler et. al. [4] with a ^3He-CF_4 also demonstrated adequate discrimination of gamma ray events. Beddingfield, et. al.[5] performed a detailed evaluation of ^{3}He chambers with a variety of gas mixtures, gas pressures, and chamber interior coatings. The results of Beddingfield et al., indicated that either N_2 or CO_2 was a good quench gas. Detectors using these quench gases were operable in gamma ray fields up to 200 rad/hr.

The triton and proton produced by thermal neutron capture in ^{3}He are relatively heavy charged particles compared to secondary electrons created by gamma ray interactions. Consequently, these heavier charged particles create ions with a limited range within the chamber as compared to the electrons. Thus, pulses due to secondary electron interactions within the chamber will have a longer rise time than those due to the triton or proton interaction.[6]

The preamplifier and amplifier time constants will influence the effects of gamma ray pile up. Short preamplifier time constants allow the chamber to operate at higher count rates because the decay time of pulse becomes shorter. However, as noted by Brown [7], the pulse amplitudes for neutron induced events may also be reduced. Furthermore, the time constant of the linear amplifier should be short for high rate conditions. Because of these considerations, this study addressed the effects of varying the preamplifier and amplifier time constants used with ^{3}He proportional chambers in high gamma-radiation fields.

This brief report describes the results of measurements with two different ^{3}He proportional chambers in high gamma-radiation fields. Measurements were performed with 1-atm, ^3He-CF_4 and 4-atm, ^3He-CO_2 chambers. Section II provides a description of the detectors and the measurement system electronics. A description of the measurements is provided in section III. The results of measurements with a $^3He-CO_2$ detector are described in section IV, and the results of measurements with a $^3He-CF_4$ detector are presented in section V. A summary is provided in section VI.

II. DETECTORS AND SYSTEM ELECTRONICS

Two different ^3He chambers were used in these measurements. Both chambers had a 1-in. OD with a nominal 16-in. active length. The inner walls of the chambers were coated with activated carbon that absorbs impurities in the gas. One of the ^3He proportional chamber was a standard Reuter Stokes design that was filled with 4 atmospheres of ^3He with approximately 2% CO_2 as a quench gas. The other detector was a special design that had 1 atmosphere of ^3He with 25% CF_4 as a quench gas to increase the electron drift velocity. This mixture was chosen based on the results of measurements performed by Koehler et. al. using a similar detector.

The detectors operated at 1200 V, which corresponded to the start of the counting plateau. The counting plateau for both detectors was essentially flat from 1200 to 1500 V. Unlike the work of Beddingfield et al, the applied detector voltage was maintained at 1200 V for all gamma radiation fields. Reduction of the voltage would reduce the gas multiplication.

A custom, charge-sensitive preamplifier with a JFET input transistor and a 1-pF feedback-capacitor (C_f) was designed for these measurements. At low count rates a 200 MΩ feedback resistor (R_f) was used while at high count rates a 22 MΩ feedback resistor was used. A simplified diagram of the charge sensitive preamplifier is shown in Fig. 1. The preamplifiers mounted directly on the end of the ^3He proportional chambers to reduce noise contributions to the detector signals. Two different amplifiers were used in these measurements. Measurements were performed using an ORTEC spectroscopy amplifier with adjustable time constants and a fast timing amplifier designed by ORNL with a 200 ns time constant. The selection of the amplifier time constants affects the pulse height distribution because of incomplete charge collection. A multi-channel analyzer was used to obtain the pulse height curves.

Measurements were performed with the proportional chambers exposed to a moderated neutron source and to a 1 Rad/hr gamma ray source. The pulse height spectra for both ^3He detectors using an ORTEC spectroscopy amplifier with a 0.25 μs time constant are shown in Figs. 2 and 3. For these measurements, the preamplifier feedback-time constant was 200 μs. The preamplifier feedback circuit consisted of a 200-MΩ resistor and a 1-pF capacitor. The pulse height spectra had a typical shape with a peak due to the capture of both the triton and the proton and exhibited the "wall effect" continuum. The "wall effect" was significant because this was a 1-inch OD chamber. The pulse height curves for the two chambers were very similar. In a low gamma radiation environment, the separation between pulses due to neutrons and gamma rays was easily achieved.

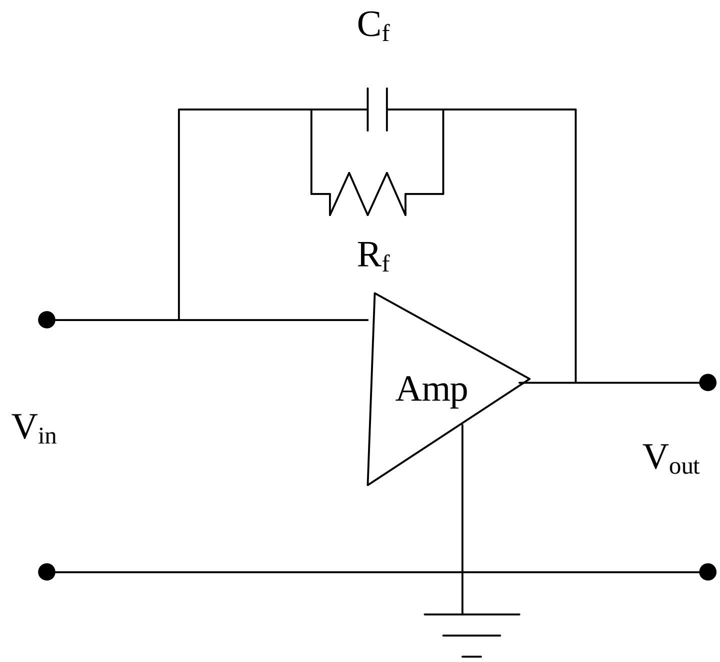

Fig. 1. Simplified diagram of a charge sensitive amplifier.

Additional measurements were performed in which the amplifier time constants were adjusted. The pulse height spectra for different amplifier time constants are shown in Fig. 4. The number of low-amplitude pulses was reduced as the amplifier time constant increased because of the ability to collect more charge with a longer time constant. However, as can be seen in Fig. 4, the separation between the low amplitude neutron events and the gamma ray events became less distinguishable. For a 0.25 μs amplifier time constant, the separation between the neutron-and gamma ray-pulses is evident in Fig. 4 around channel 75. A separation between the gamma ray events and the low amplitude neutron events was slightly evident with a time constant of 1 μs. There was no direct separation between the low amplitude neutron events and the gamma ray events using an amplifier time constant of 2 μs. As the amplifier time constant was increased the pile up of gamma ray events became more significant and had a greater affect on the pulse height distribution. For strictly pulse counting applications, it was best to use shorter amplifier time constants to lessen the effects of gamma ray pile up.

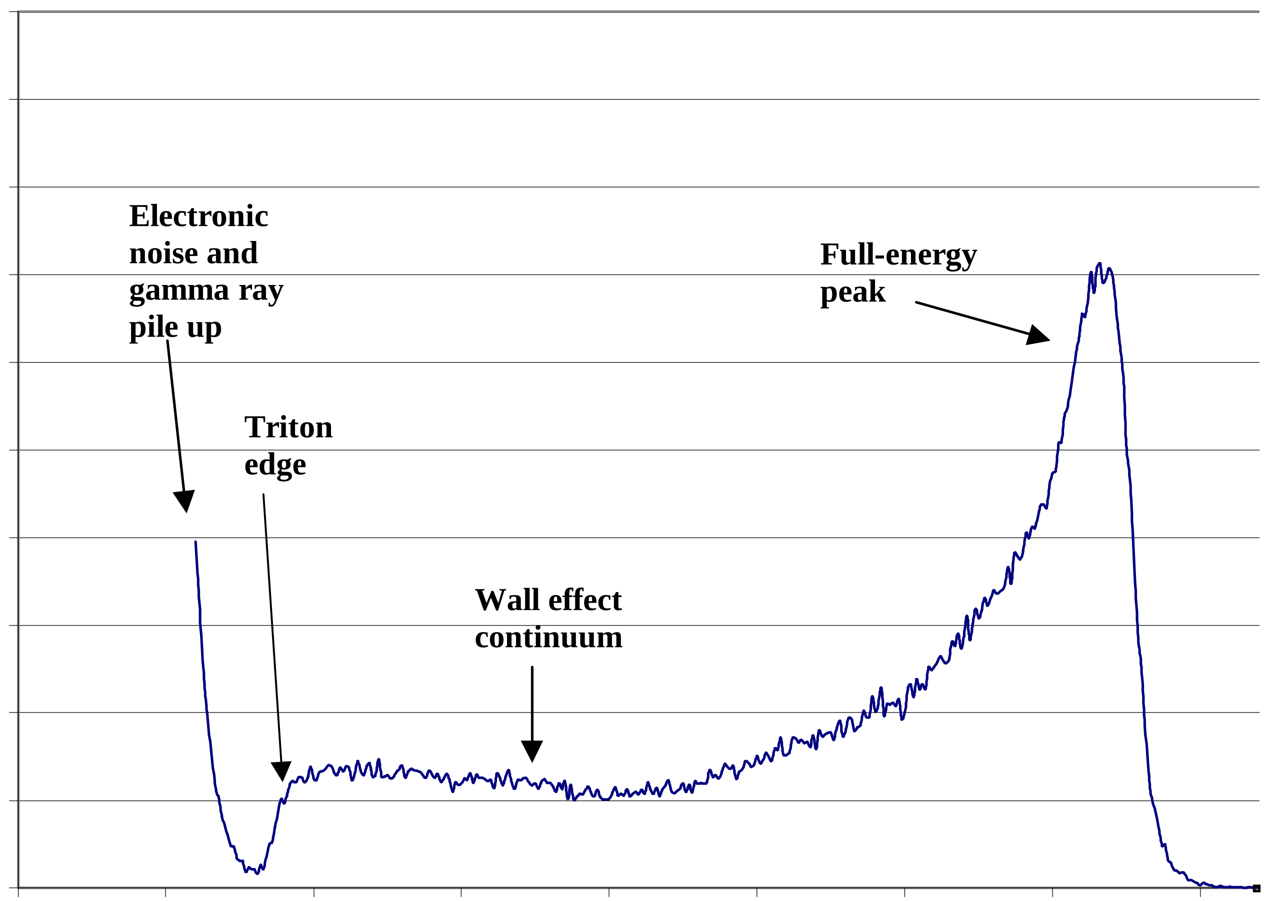

Fig. 2. Pulse height curve for standard 4-atm, ^{3}He-CO_2 proportional chamber operated at amplifier time constant and a 200 ms preamplifier time constant.

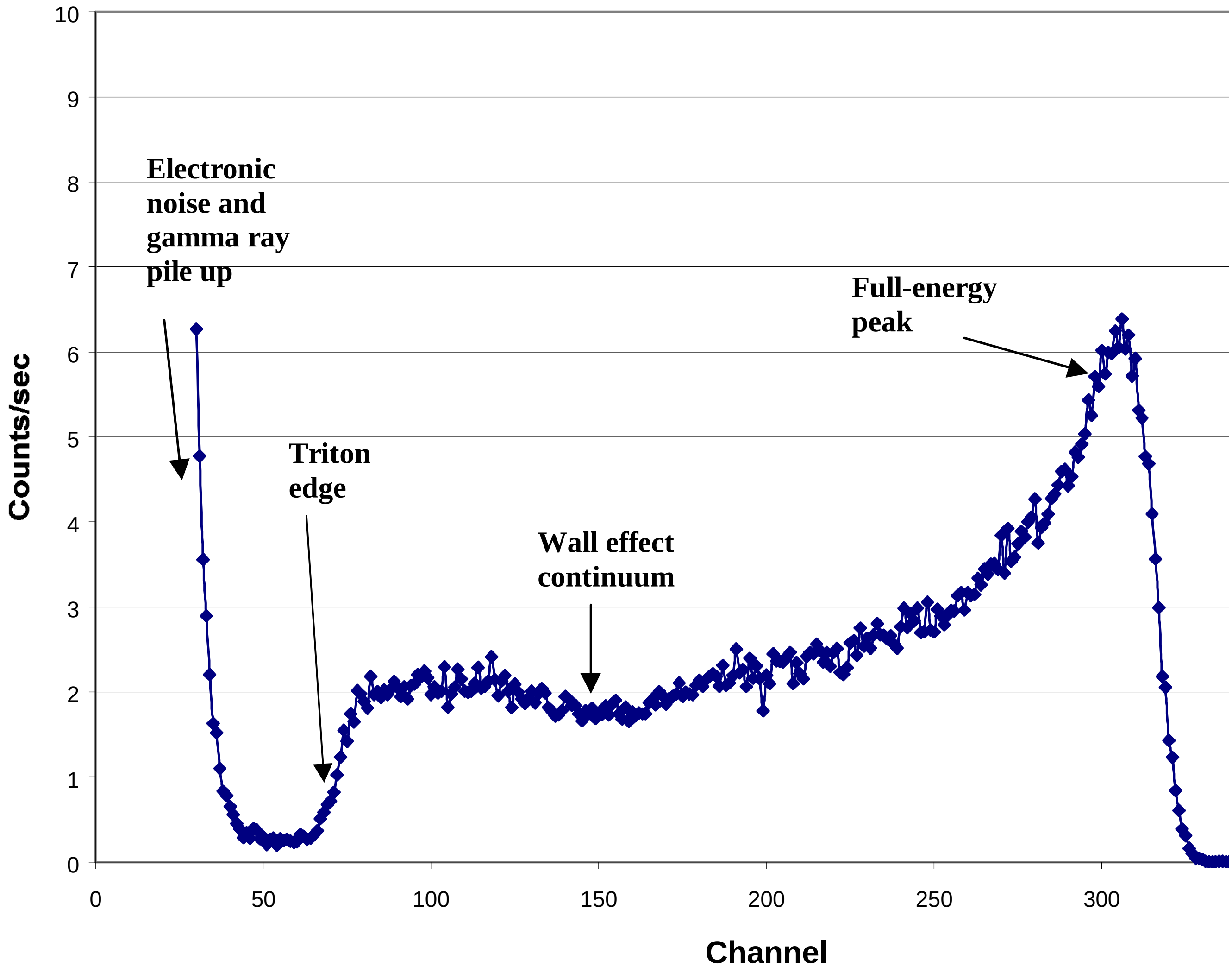

Fig. 3. Pulse height curve for 1-atm, $^{3}He\text{-}CF_4$ proportional chamber operated at 1200 V with a constant and a 200 ms preamplifier time constant.

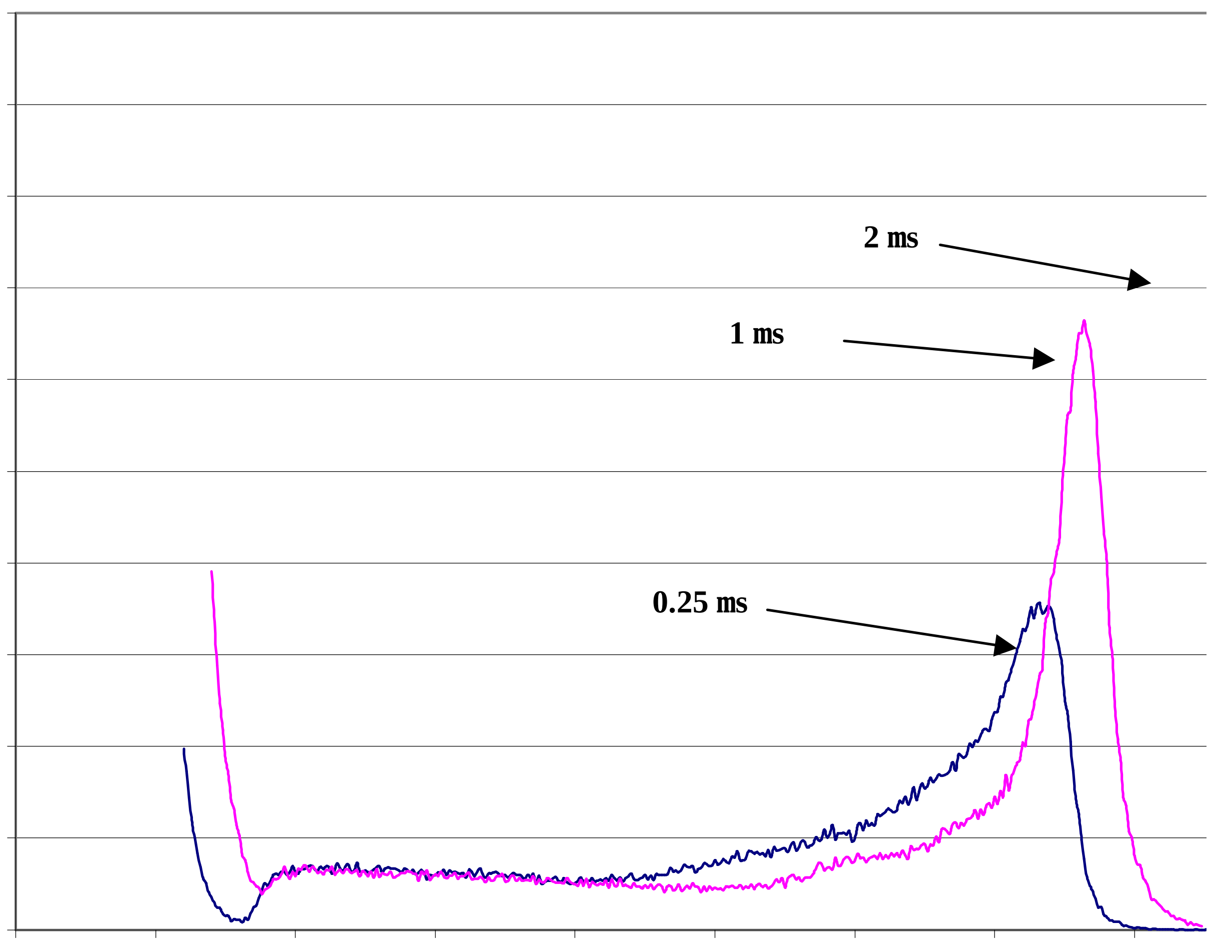

Fig. 4. Pulse height curve for standard 4-atm, $^{3}He\text{-}CO_2$ proportional chamber operated at 1200 amplifier time constants and a 200 ms preamplifier time constant.

A modification was made to the preamplifier time constant to allow for higher count rate operation by changing the feedback resistor from 200 MΩ to 22 MΩ. The reduction of the feedback resistance increased the preamplifier noise but it allowed the chamber to operate at higher count rates by shortening the decay of the preamplifier pulses. In high radiation fields the pulse pile up was significant. The pulse height spectra obtained using this preamplifier are shown in Fig. 5. The pulse height resolution was reduced because of the incomplete charge collection with the shorter preamplifier time constants. For strictly pulse counting applications, the resolution of the full-energy peak was not necessary. The full-energy peaks did not coincide because the amplifier gain was changed for different time constants. The full-energy peak in the pulse height spectra was essentially absent for amplifier time constants of 0.25 μs and 0.5 μs and was significantly reduced for a 1-μs amplifier time constant. A 2-μs time linear amplifier constant was used to obtain a similar resolution to that obtained with the standard preamplifier design. As the linear amplifier time constants were lowered many more of the neutron counts were low amplitude as a consequence of incomplete charge collection. Selection of the preamplifier time constant resistor and the linear amplifier time constant was strongly dependent on the electron drift velocity for the gas used in the chamber.

III. DESCRIPTION OF MEASUREMENTS

The ^{3}He detectors were exposed to a ^{137}Cs gamma ray source to simulate the dominant gamma ray characteristics of spent nuclear fuel. The detector was positioned vertically above a small cylindrical source. This allowed gamma rays to shine directly up the axis of the detector thereby increasing the probability for gamma ray interactions with chamber walls. Thermoluminescent dosimeters (TLDs) were located on the bottom, middle, and top of the detectors to provide measurements of the gamma ray field. The reported gamma ray dose was the average of the dose as measured by the three TLDs as provided in Table 1.

Table 1. Measured gamma radiation field dose rates

Approximate average (rad/hr)	Bottom (rad/hr)	Middle (rad/hr)	Top (rad/hr)
0.5	0.68	0.57	0.40
30	50	33	16
200	279	186	133
300	463	288	187

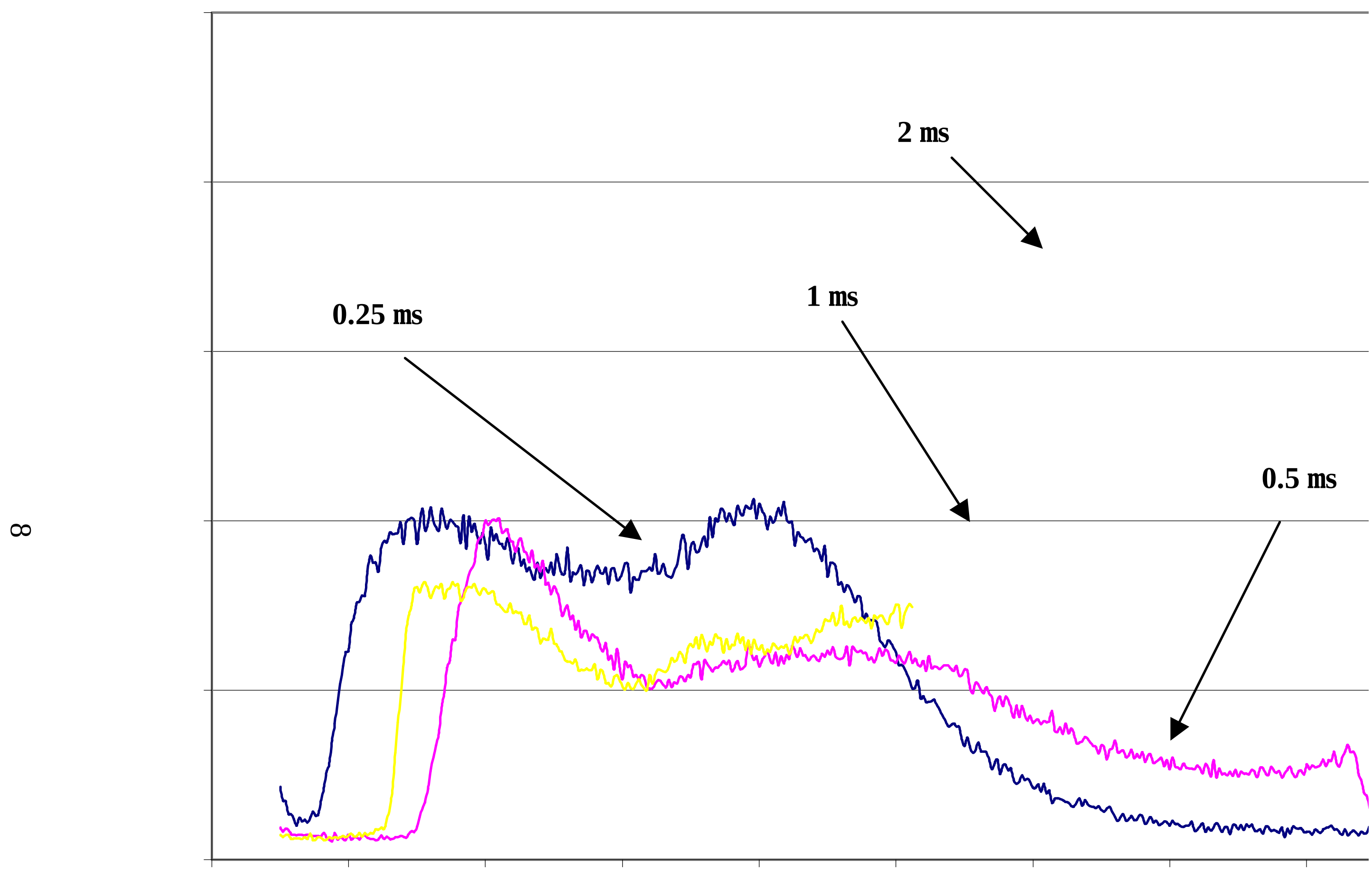

Fig. 5. Pulse height curve for standard 4-atm, ^{3}He-CO_2 proportional chamber operated a amplifier time constants and a 22 ms preamplifier time constant.

A ^{252}Cf (~10^5 n/s) source in the center of a polyethylene moderator was positioned adjacent to the detector. The polyethylene moderator had a ~1-in ID and a 5-in OD. The source-detector is shown in Fig. 6.

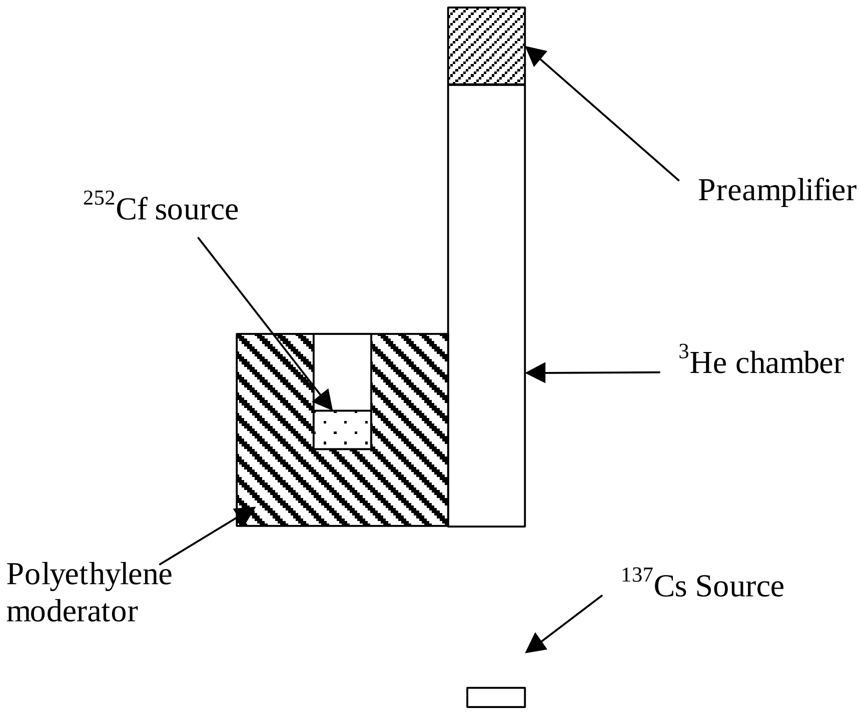

Fig. 6. Sketch of source-detector configuration.

IV. RESULTS WITH ^3He-CO_2 DETECTOR

Measurements were performed with the standard ^3He-CO_2 chamber exposed to a variety of gamma radiation fields. These measurements were performed with the detector operated at 1200V and used a preamplifier with a 22 µs time constant. The amplifier time constant was varied using an ORTEC spectroscopy amplifier and an ORNL fast timing amplifier.

Measurements were performed with an amplifier time constant of 0.25 µs. The resulting pulse height curves are shown in Fig. 7. As can be seen, the contribution of gamma ray events to the pulse height spectra increased as the gamma ray field increased. Additional measurements were performed for the same radiation fields using a fast timing amplifier with a 0.2 µs time constant. The results of these measurements are shown in Fig. 8. Again, the pulse height spectra became more affected by the gamma ray pile up as the gamma ray field increases.

For these neutron-counting measurements, a threshold was selected to eliminate pulses due to gamma ray pile up. Consequently, low-amplitude neutron capture pulses were also eliminated and reduced the efficiency of the ^{3}He chamber. The counting efficiency of the $^{3}He\text{-}CO_2$ detector was defined as the ratio of counts above the gamma ray threshold to the counts above the threshold for no gamma radiation field. The counting efficiency for the detectors was slightly improved if a faster amplifier time constant was used as evident in Table 2 because fewer pulses from gamma ray events were counted. The results were also consistent with those of Beddingfield et al using a 4 atmosphere $^{3}He\text{-}CO_2$ chamber for a 200 Rad/hr gamma field.

Table 2. $^{3}He\text{-}CO_2$ counting efficiency for various gamma ray fields

Gamma radiation field (rad/hr)	Efficiency (0.25 μs time constant)	Efficiency (0.2 μs time constant)
0.5	100%	100%
30	95%	95%
200	35%	43%
300	31%	40%

The reduction in the amplitudes of the neutron pulse may have resulted from to the increased current in the chamber as the gamma field increases. Because the preamplifier supplied the high voltage to the chamber through a load resistance, leakage currents due to electrons from gamma ray interactions most likely reduced the voltage that was supplied to the chamber. Therefore, the gas multiplication was reduced. Unfortunately, the magnitude of the leakage current was not measured.

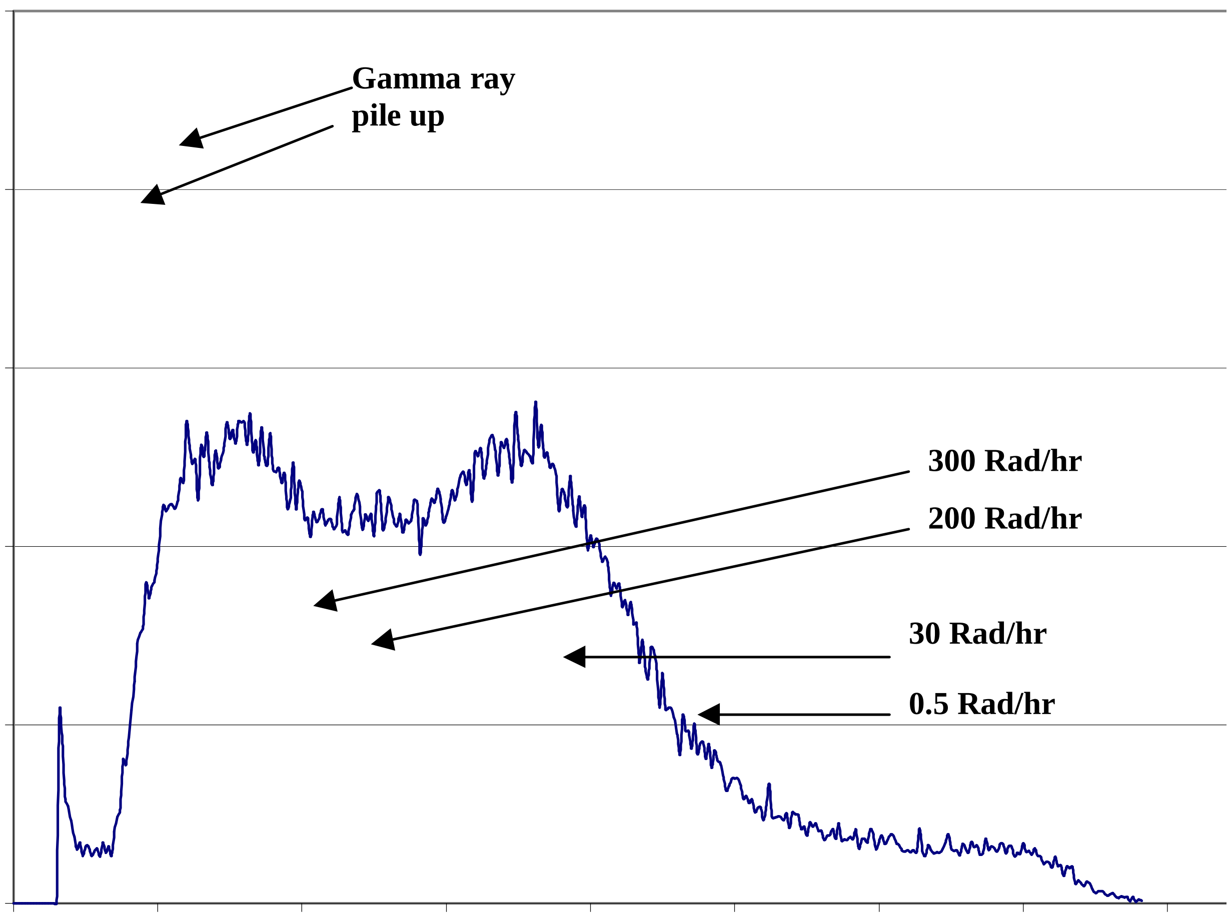

Fig.7. Pulse height curve for standard 4-atm, ^3He-CO_2 proportional chamber operated at 1200 amplifier time constants and a 22 ms preamplifier time constant in varying gamma radiation fields.

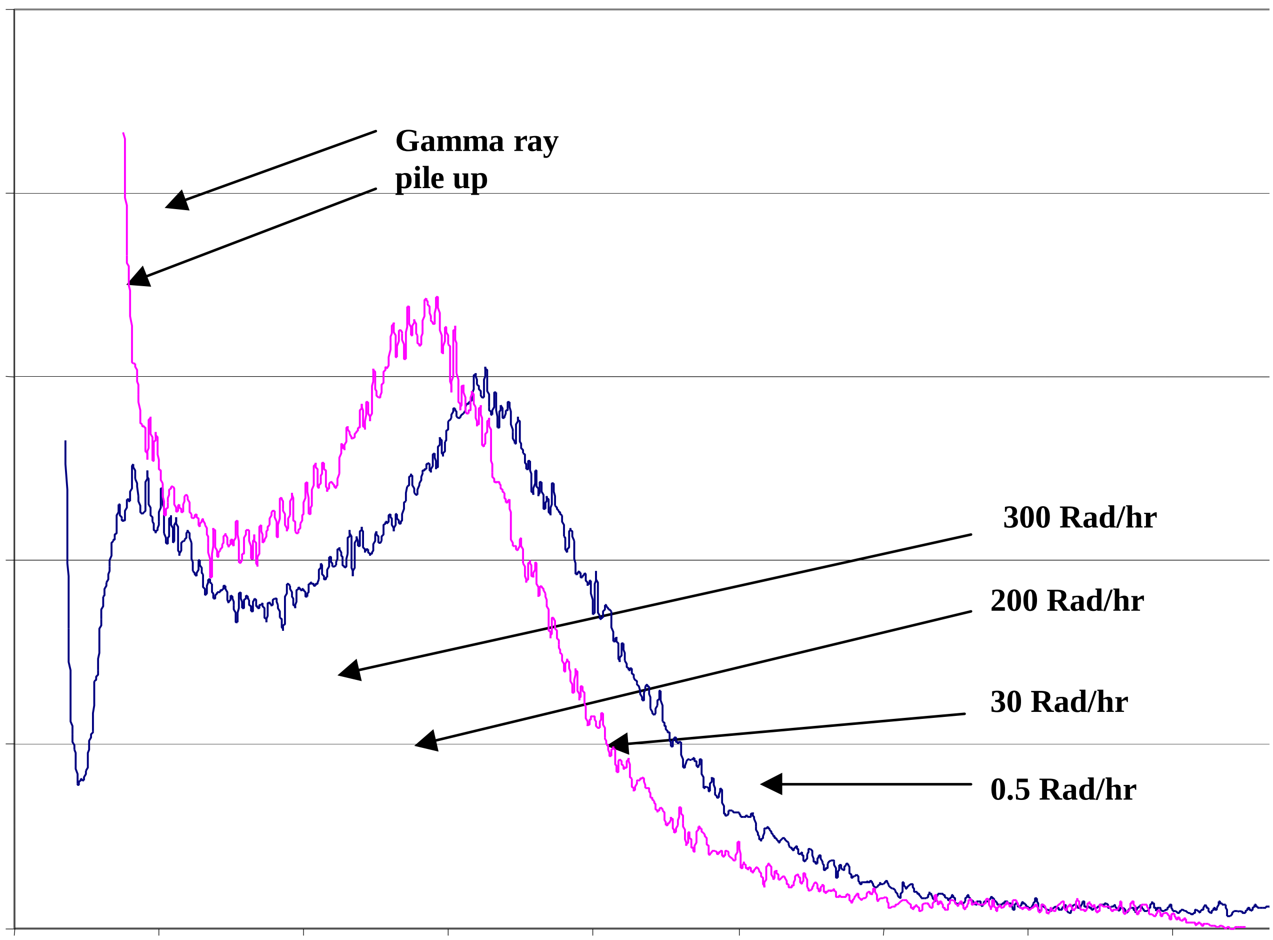

Fig. 8. Pulse height curve for standard 4-atm, ^{3}He-CO_2 proportional chamber operated at 1200 amplifier time constants and a 22 ms preamplifier time constant in varying gamma radiation fields.

V. RESULTS WITH ^{3}He-CF_4 DETECTOR

Measurements with the ^{3}He-CF_4 were performed in various gamma radiation fields with a preamplifier with a 22-μs feedback time constant. Measurements were performed using an ORTEC spectroscopy amplifier with a 0.25 μs time constant and with a fast timing amplifier with a 0.2 μs time constant. The pulse height spectra for the two different amplifiers are shown in Figs. 9 and 10. As with the ^{3}He-CO_2 chamber, the energy resolution was better if longer amplifier time constant were used. The energy resolution of the ^{3}He-CF_4 chamber was better than the ^{3}He-CO_2 chamber; however, the counting efficiency of the ^{3}He-CF_4 was less than the ^{3}He-CO_2 chamber. The energy resolution for the ^{3}He-CF_4 was better because more quench gas was in this chamber. The quench gas greatly reduced the range of the triton and proton in the chamber. The counting efficiency of the ^{3}He-CF_4 detector was defined as the ratio of counts above the gamma ray threshold to the counts above the threshold for no gamma radiation field. The counting efficiency for the detectors was slightly improved if a faster amplifier time constant was used as shown in Table 3.

Table 3. ^{3}He-CF_4 counting efficiency for various gamma ray fields

Radiation field (rad/hr)	Efficiency (0.25 μs time constant)	Efficiency (0.2 μs time constant)
0.5	100%	100%
30	87%	93%
200	11%	14%
300	8%	11%

As the gamma radiation field increased, the number of electrons produced in the chamber increased. These electrons produced a current in the chamber that may have reduced the actual voltage that was supplied to the chamber because of leakage of this current through the load resistor. Measurements were performed with increased supply voltages; however, both the neutron and gamma ray pulse-amplitudes increased. Therefore, the counting efficiency did not increase with increased voltage.

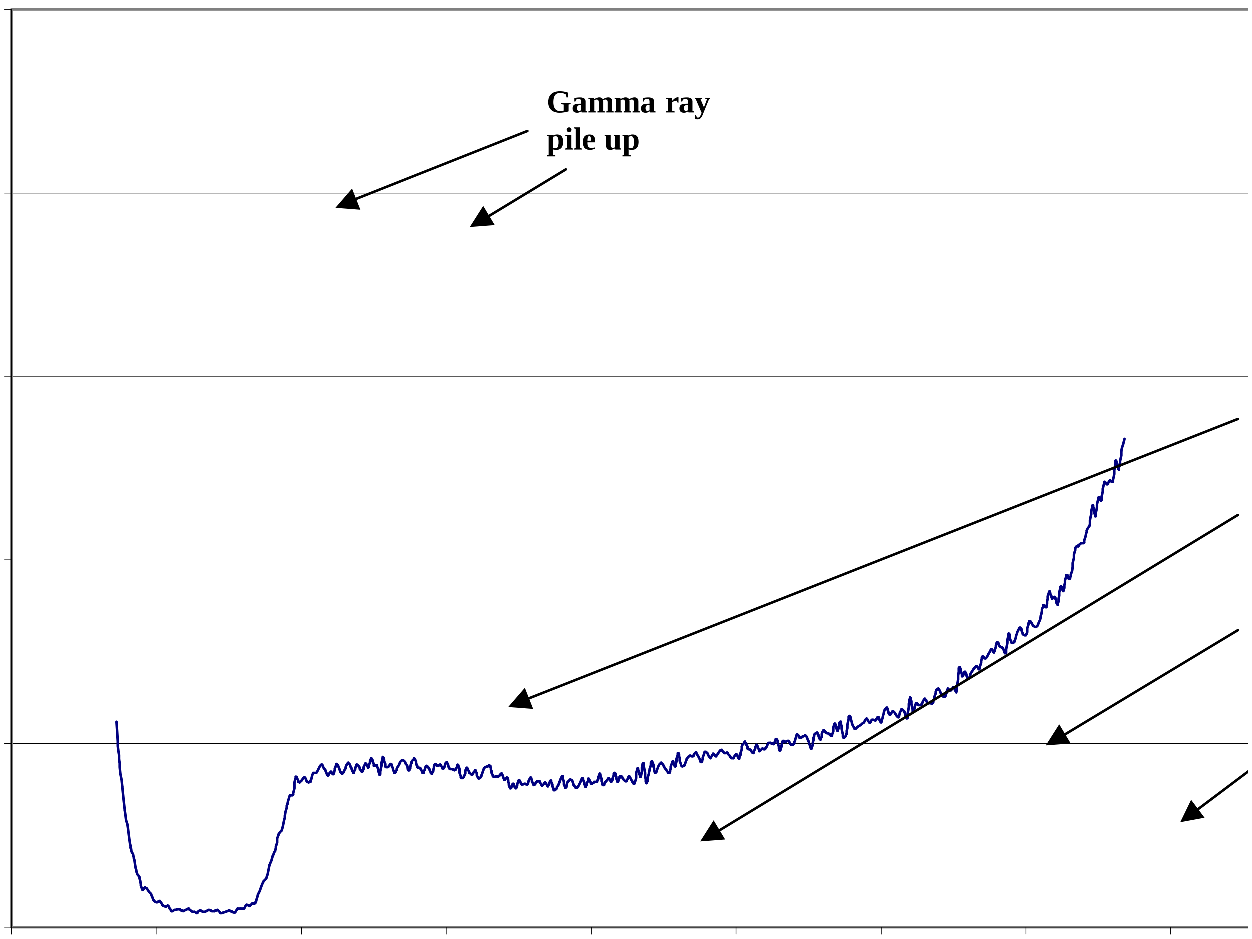

Fig. 9. Pulse height curves for 1-atm, ^{3}He-CF_4 proportional chamber operated at 1200 V with a constants and a 22 ms preamplifier time constant in varying gamma radiation fields.

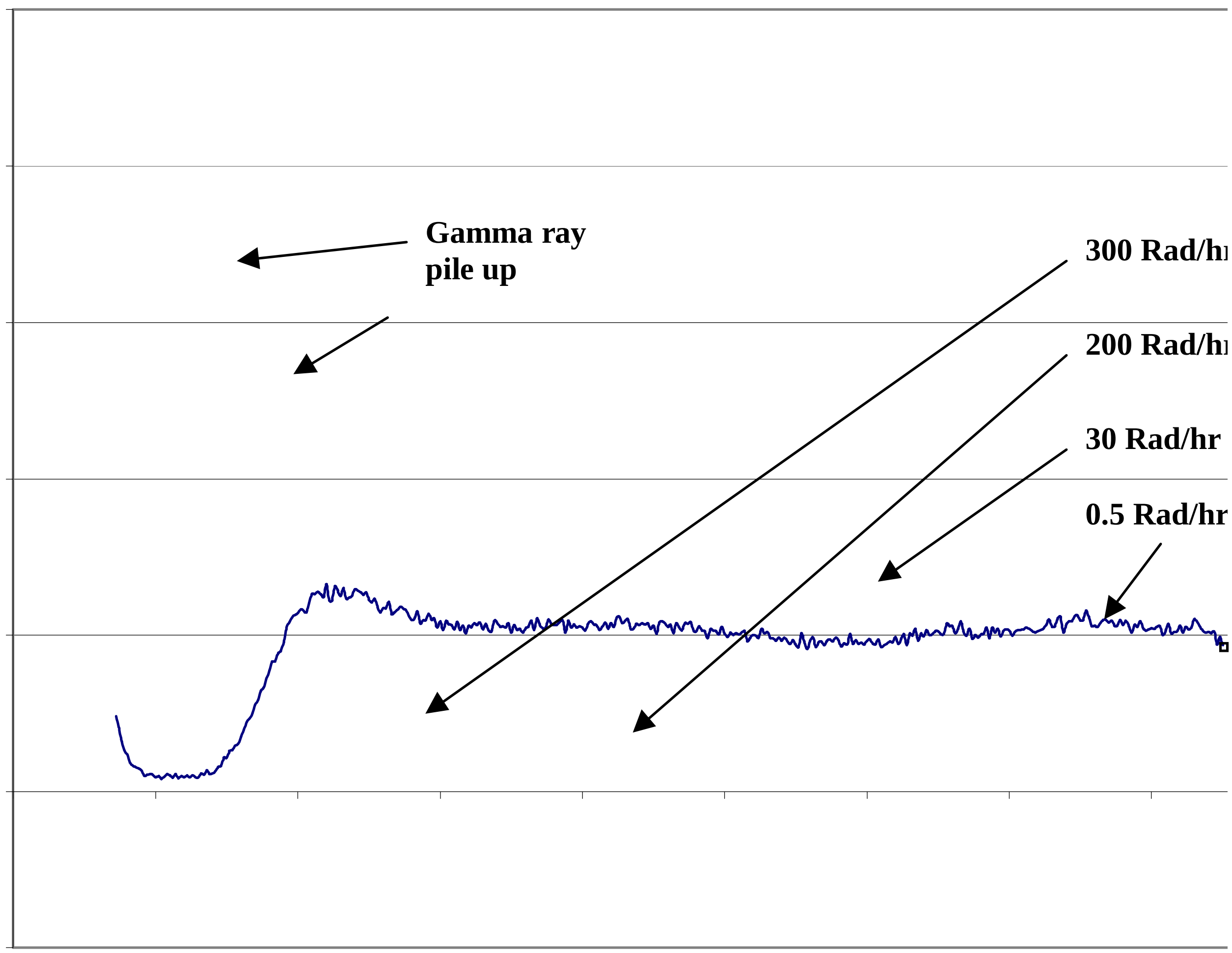

Fig. 10. Pulse height curves for 1-atm, $^{3}He\text{-}CF_4$ proportional chamber operated at 1200 V with constants and a 22 ms preamplifier time constant in varying gamma radiation fields.

VI. SUMMARY

The results of these measurements demonstrated that ^3He detectors with appropriate quench gases could be used for neutron measurements in high gamma ray radiation fields. The efficiency of the ^3He detector was improved with proper selection of the preamplifier and amplifier time constants. For strictly pulse counting measurements, the resolution of the chamber was not as important, and complete charge collection for each event was not required. Hence, faster preamplifier and amplifier time constants provided better discrimination against gamma ray pile up events. The counting efficiency for the 4-atm, $^3He\text{-}CO_2$ chamber increased approximately 8% when the amplifier time constant was reduced from 0.25 to 0.2 μs. while the counting efficiency for the 1-atm, $^3He\text{-}CF_4$ chamber increased only 3% for the same change in amplifier time constants. If higher resolution was required, longer time constants would have been used and the counting efficiency of the chambers would have been significantly reduced. The results presented for the 4atm, $^3He\text{-}CO_2$ chamber were consistent with those presented by Beddingfield et al. The results demonstrated that the 4-atm, $^3He\text{-}CO_2$ 1-in. OD chamber had a higher counting efficiency than the 1-atm, $^3He\text{-}CF_4$ 1-in. OD chamber although the energy resolution of the $^3He\text{-}CF_4$ chamber was better than that for the $^3He\text{-}CO_2$ chamber.

The results of these measurements did not indicate whether a 4-atm, $^3He\text{-}CF_4$ chamber would have better or similar performance to the 4-atm, $^3He\text{-}CO_2$ chamber. Additional measurements with the ^3He at the same pressure should be performed to determine this. Measurements with different diameter chambers should also be performed to reduce the wall effect. Finally, the leakage current across the load resistor should be measured to determine the exact change in the bias supplied to the chambers as the radiation field increased.

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