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PULSE RISE TIME CHARACTERIZATION OF A HIGH PRESSURE XENON GAMMA DETECTOR FOR USE IN RESOLUTION ENHANCEMENT

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Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
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PULSE RISE TIME CHARACTERIZATION OF A HIGH PRESSURE XENON GAMMA DETECTOR FOR USE IN RESOLUTION ENHANCEMENT

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ABSTRACT

High pressure xenon ionization chamber detectors are possible alternatives to traditional thallium doped sodium iodide (NaI(Tl)) and hyperpure germanium as gamma spectrometers in certain applications. Xenon detectors incorporating a Frisch grid exhibit energy resolutions comparable to cadmium/zinc/telluride (CZT) (e.g. 2% @ 662keV) but with far greater sensitive volumes. The Frisch grid reduces the position dependence of the anode pulse risetimes, but it also increases the detector vibration sensitivity, anode capacitance, voltage requirements and mechanical complexity. We have been investigating the possibility of eliminating the grid electrode in high-pressure xenon detectors and preserving the high energy resolution using electronic risetime compensation methods. A two-electrode cylindrical high pressure xenon gamma detector coupled to time-to-amplitude conversion electronics was used to characterize the pulse rise time of deposited gamma photons. Time discrimination was used to characterize the pulse rise time versus photo peak position and resolution. These data were collected to investigate the effect of pulse rise time compensation on resolution and efficiency.

Introduction

Gamma radiation spectrometers with a combination of high energy resolution, large sensitive volume and thermal stability are required for a variety of field applications including nuclear waste-site characterization, military surveillance, treaty verification and well logging. Detectors based on high-purity germanium (HPGe) offer excellent energy resolution, but are relatively expensive and must be operated at low temperature, which is inconvenient in the field. Scintillation-based spectrometers such as NaI(Tl) operate at room temperature, but the pulse amplitudes are affected by temperature variations and the energy resolution is relatively poor. Solid state room temperature detectors based on compound semiconductors such as Cadmium Zinc Telluride (CZT) and Mercuric Iodide (HgI_2) are under development, but the detector size and performance is currently limited by fundamental material problems and low hole mobility.

Highly purified and compressed xenon has emerged as an alternative, thermally stable detection medium for high resolution gamma radiation spectroscopy in the energy range < 5 MeV.[1-8] Detectors based on compressed xenon offer a unique combination of properties that are complimentary to existing commercial spectrometers and are particularly attractive for field applications. The important xenon detector specifications in comparison to both NaI(Tl) and HPGe detectors are shown in Table 1.

High pressure xenon gridded ionization chambers currently provide a room temperature energy resolution intermediate to NaI(Tl) and HPGe. Furthermore, the high atomic number of xenon (Z=54) results in an efficiency comparable to that of NaI(Tl) and the relatively large ionization energy of a noble gas allows the detector to operate

over a wide range of temperatures with negligible channel drift or energy resolution degradation. Finally, these fluid based spectrometers are not susceptible to the problems associated with crystallographic defects including radiation damage, and can be constructed in a variety of geometries.

Previous prototype detectors constructed in both planar and cylindrical geometries and incorporating a Frisch grid electrode have demonstrated the excellent spectroscopic performance of high-pressure xenon detectors.[1-8] The role of the grid electrode is to shield the anode from the ionization region to eliminate the dependence of the anode pulse shape on the ionization coordinate. However, the Frisch grid also introduces complications including enhanced vibration sensitivity, an increased anode capacitance and increased detector voltage requirements. Recent experiments performed on planar semiconductor detectors suggest that it may be possible to eliminate the grid electrode entirely and use electronic methods to preserve the energy resolution while significantly improving the overall detector performance.[9]

Here we investigate the general performance and pulse risetime distribution in a specially constructed two-electrode (i.e. without a Frisch grid) high-pressure xenon ionization chamber. The results indicate that the two-electrode design offers numerous practical advantages in comparison to the traditional three-electrode configuration, but will require additional electronic signal conditioning in order to provide a competitive energy resolution.

Experimental

Xenon Preparation

The requirements and methodologies for achieving and maintaining the necessary xenon purity have been addressed elsewhere and are only briefly summarized here.[7] An ultra-high vacuum system containing both high-temperature getters and a titanium spark purification chamber was used to purify the xenon and to prepare and fill the detector. The lower limit of the electron lifetime in xenon was established by monitoring the duration of pulses produced by cosmic muons using a gridded ionization chamber located inside the spark purification chamber. The xenon purity was considered acceptable when the lower limit of the electron lifetime within the spark purification chamber exceeded 3 ms. The detector was filled with the purified xenon to a density of approximately 0.5g/cc by weight measurement and maintained at this density for all of the data reported in this work. The effects of xenon density on detector energy-resolution have been reported previously and will not be discussed here.[2,7]

Detector Design

Figure 1 is a schematic diagram illustrating the coaxial geometry of the detector. The thin-walled stainless steel pressure vessel was designed to contain up to 10.3 MPa of xenon and has a sensitive volume of 90 cm^3. The anode and cathode feedthroughs and the vacuum/fill tube were welded into 0.635 cm thick circular end caps. The anode electrode is a solid stainless steel 0.5 cm diameter rod and the cathode electrode consists of a silver coating deposited on the inside surface of an Alumina ceramic tube with an inner diameter of 3.35 cm. High voltage was supplied using a commercial power supply incorporating a low-pass filter circuit to reduce the power supply ripple. The anode

pulses were fed to a charge sensitive pre-amplifier attached directly to the external feedthrough.

Test Configuration

Pulse rise time response was investigated by attaching the pre-amplifier to the following EG&G Ortec modules: 671 Spectroscopy Amplifier(SA), 552 Pulse Shape Analyzer (PSA), 567 Time to Amplitude Converter (TAC), 427A Delay Amplifier, and a personal computer based ADCAM Multi-Channel Analyzer. The block diagram of instrumentation setup is shown in Figure 2. The bipolar output of the SA provides a time dependency at crossover which can be processed by the TAC. The start and crossover provide start and stop gates to the TAC which then converts the time to an amplitude pulse compatible with the traditional MCA. Discriminator controls on the TAC were set to maximum limits for acquiring a rise time spectrum for all detector pulses. Subsequently, the discriminators and a delay amplifier were used to allow only selected time ranges of detector pulses to be gated into the MCA. For all of the pulse height spectra reported here the pulse shaping time was between 2 and 3 μs.

Results

Five selected time regions (R1-R5, Figure 3) were measured to determine the dependency of resolution to rise time and to infer aspects of event locality and charge collection. The rise time pulse distribution with several highlighted time regions is shown in Figure 3.

Figure 4 shows a typical uncompensated (i.e. all risetimes included) pulse height distribution obtained with the detector exposed to a ^{137}Cs calibration source. The FWHM energy resolution for the 662keV line is approximately 7% which is significantly worse than the typical 2-3% FWHM resolution obtained in gridded xenon spectrometers. The low energy tailing of the photopeak is due to the expected variation in the anode pulse risetimes. The full width at half maximum of the test pulse generator was 15-16keV. The individual time region resolutions of photopeak full width at half maximum height are shown in Table 2 and Figure 5.

Discussion

The pulse risetime distribution of Figure 3 exhibits a shoulder on the short risetime side of the main distribution peak. This was somewhat unexpected and suggests that there may be a local inner maximum in the gamma-ray interaction distribution within the detector. A detailed Monte Carlo simulation including source location and xenon density as adjustable parameters would be necessary in order to understand the possible mechanisms for this apparent ionization concentration. However, here we are primarily interested in investigating the relationship between the risetime distribution and the spectral response of the detector. The interaction simulations would be an interesting follow up to the current investigation and we do point out that the photoelectric efficiency for 662keV gamma-rays in 0.5 g/cc of xenon is less than 1% so that multi-location interactions are expected to dominate.

One important feature of cylindrical ionization chambers is the 1/r dependence of the electric field magnitude. For all of the data reported in this manuscript, the cathode

voltage was maintained at –5kV which provides the electric field distribution illustrated in Figure 6. The field magnitude varies from a maximum near 10 kV/cm at the anode to a minimum of approximately 1.5 kV/cm near the cathode. It has been previously shown that the drift velocity of electrons in high pressure xenon saturates at a value near 10^5 cm/s at electric fields above 2kV/cm. Therefore, despite the 1/r field dependence, the drift velocity of the electrons is constant across most of the detector and the maximum drift time is approximately 15 microseconds.

It was anticipated that spectral improvements could be gained by selecting small rise time regions of pulses in order to eliminate the variations in the anode pulse shapes. As with other ionization type detectors, rise time is related to the distance electrons must travel to be collected as a pulse. If all the charge arrives within a short period, the pulse will have a quick rise to peak energy and be more suitable for energy sorting. The various collected pulse height spectra are shown in Figure 5. The uncompensated spectrum (FULL) developed a photopeak resolution of 7.6% using the 662 keV gamma of ^{137}Cs. By examination, it is evident that the short rise time pulses provide better resolution. As the time region was increased, the resolution continued to degrade to the overall resolution.

One possible explanation for the decrease in energy resolution with increasing risetime is impurities in the xenon. As stated above, the electron lifetime in xenon is an indirect measure of the xenon purity and was initially over 3 ms. However, the inside surfaces of the xenon detector have a finite outgassing rate that is strongly dependent on cleaning and bakeout procedures. Over time, as the impurity level increases, the mean electron lifetime in xenon decreases and eventually results in incomplete charge

collection. This effect would be largest for ionization events with a long drift length (i.e. originating near the cathode electrode). We have previously demonstrated that, with proper bakeout procedures, a xenon detector can operate for extended periods (ca. years) before the impurities rise to a detrimental level. The detector geometry may also affect the relative peak to Compton ratio for various risetime regions. That is, gamma-rays that Compton scatter in the outer regions of the cylindrical detector are more likely to leave the detector after the initial interaction than interactions that occur deeper near the anode electrode. It was further observed that energy calibration shifted a few keV with the rise time. Since each time region showed better resolution (except for R5) than collecting all pulses, the shift in energy is a resolution factor along with rise time.

Additional important performance parameters were investigated including vibration sensitivity, anode capacitance and detector voltage requirements. All of these parameters were significantly improved in the two electrode detector in comparison to the traditional gridded device.

Conclusions

The risetime distribution and energy resolution in a specially constructed two-electrode cylindrical high pressure xenon ionization chamber have been analyzed. Pulse height spectra were obtained from various anode pulse risetime regions within the detector. As expected , the energy resolution for all risetime regions was superior to the spectra obtained by collecting all pulses. However, it was observed that the detector energy resolution decreased with increasing risetime and one possible explanation is the presence of electron salvaging impurities in the high pressure xenon detection medium.

Pulse height spectroscopy from selected risetime regions thus provides important information on specific detector performance parameters. Future work should include Monte Carlo simulations as a function of gas density and gamma-ray energy as well as additional risetime studies as a function of various detector performance parameters including gas purity.

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Table 1. Gamma Detector Characteristics

Type	Resolution @662keV	Operational Temp	Density g/mL	Atomic number (Z)
Xenon	~ 2%	variable	0.5-1.0	54
NaI(Tl)	~ 8%	~298K	3.67	11(Na), 53(I)
HPGe	< 0.5%	~77K	5.32	32

Table 2. Photopeak Resolution Dependency On Pulse Rise Time

Rise Time Region	%FWHM @662 keV	Peak Shift keV	%Pulse Abundance
Full	7.6	0	100
R1	3.1	+10	5.4
R2	4.0	0	7.2
R3	4.0	0	9.5
R4	6.2	-15	5.8
R5	7.3	-25	1.6

Figure Captions

Figure 1. Schematic diagram illustrating the detector geometry.

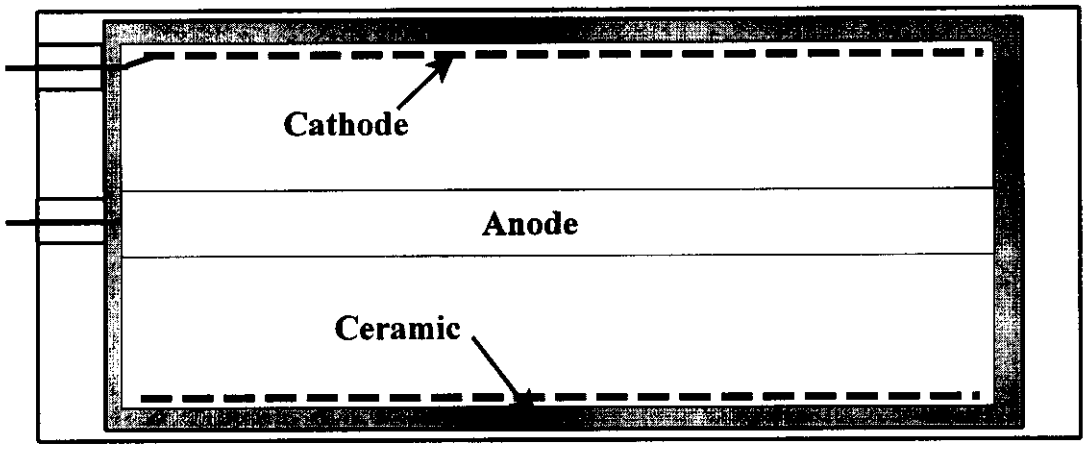
Figure 2. Electronic function module interconnection for pulse rise time distribution and spectral data collection. Only one MCA was used for all measurements.

Figure 3. Pulse rise time distribution from side illumination with ^{137}Cs source. The shaded bars are selected time regions (R1-R5) for test spectral data collection.

Figure 4. Pulse height spectrum for ^{137}Cs.

Figure 5. Representative ^{137}Cs spectra obtained at various pulse rise time regions. Data are normalized to photopeak height and energy.

Figure 6. Internal detector bias voltage field profile as distance from center to outer electrode radius.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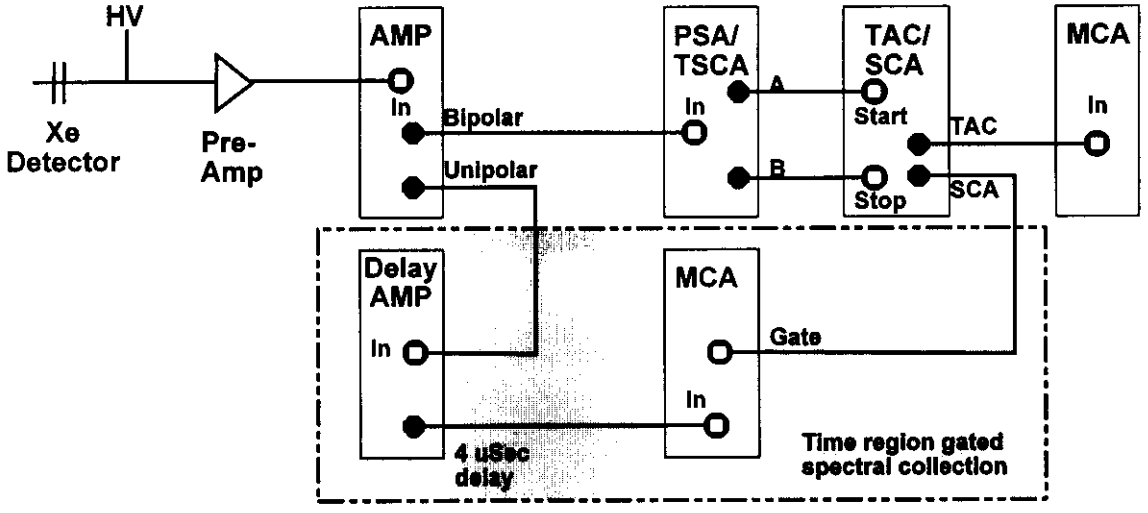
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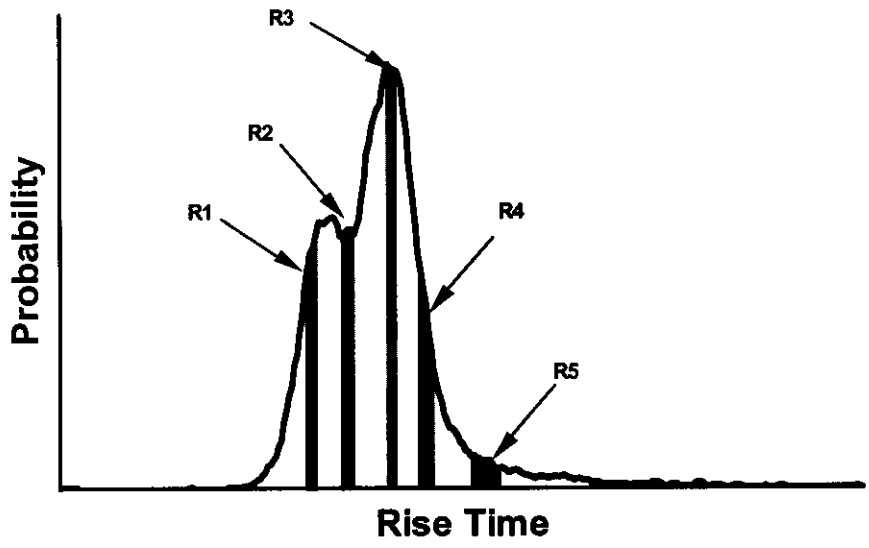
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R2
R1
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R5
Probability
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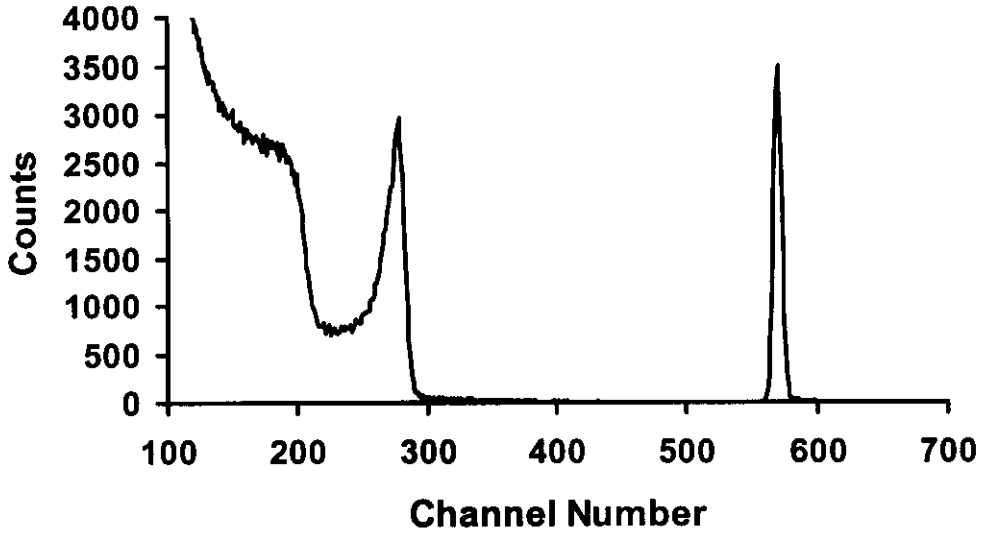
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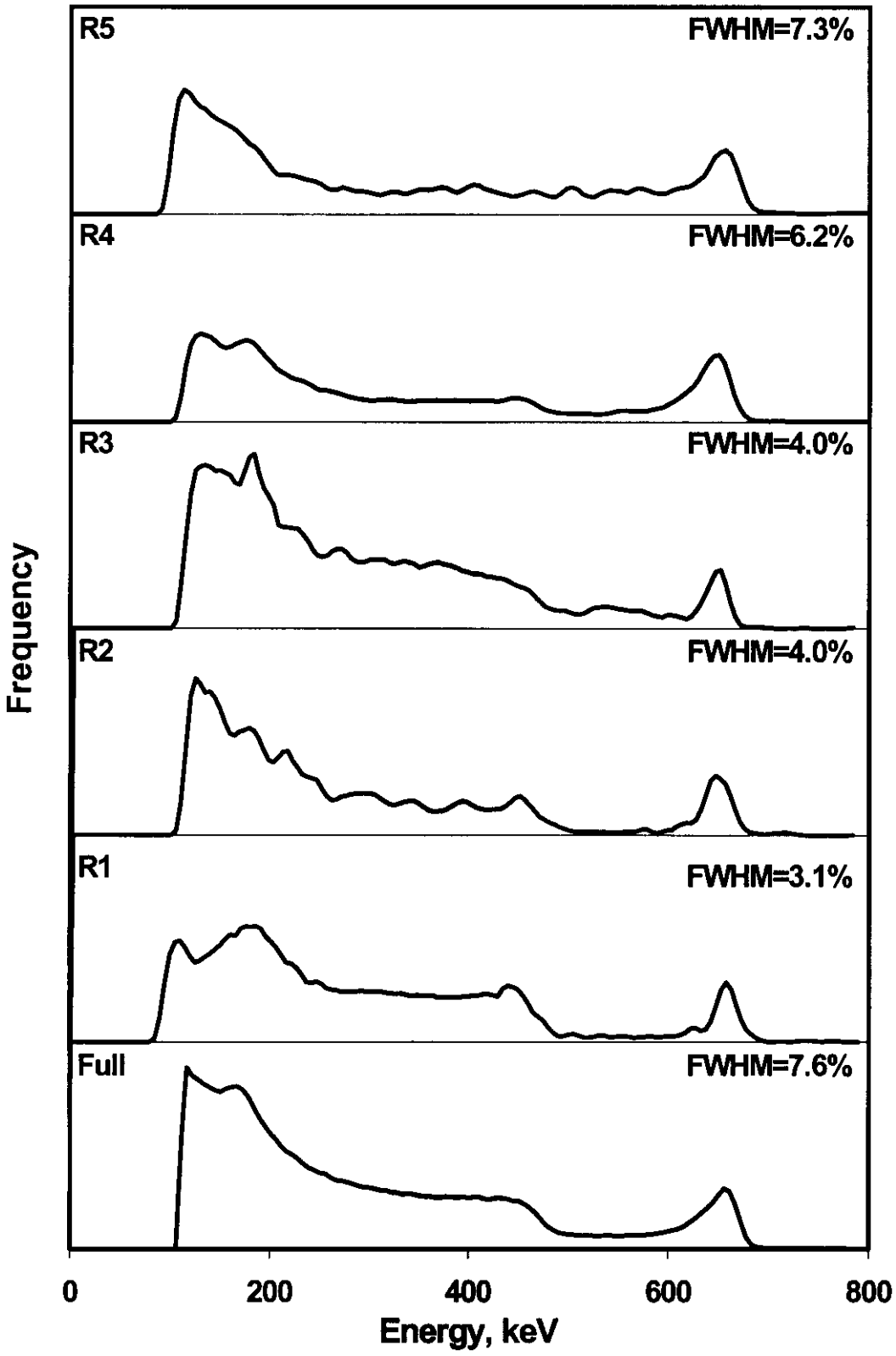
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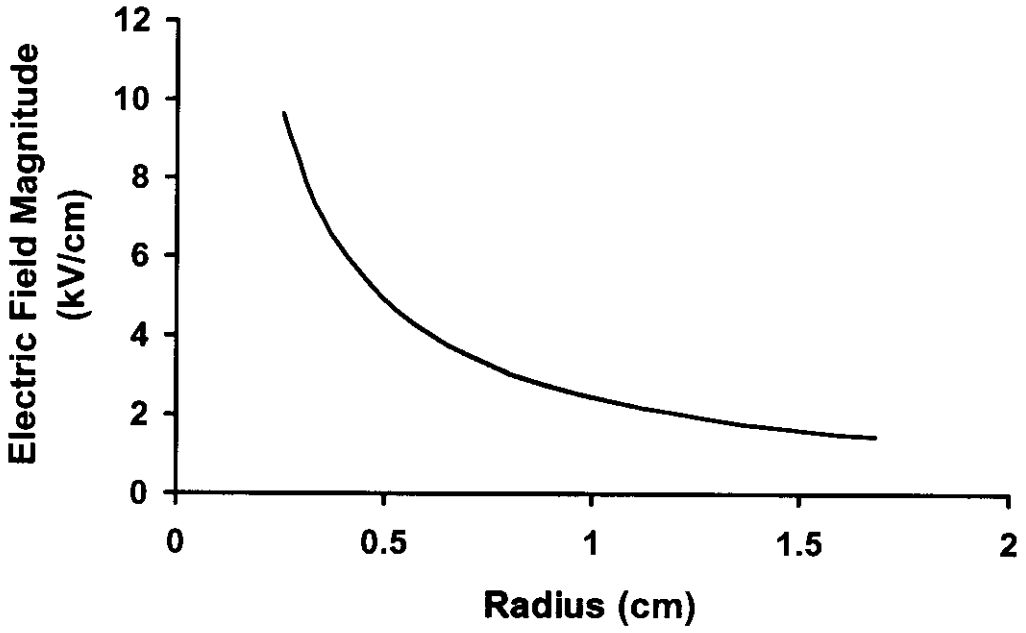
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