Nuclear Emissions During Acoustic Cavitation
(Supplemental #1 for Science Online)

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This supplement provides the following data and information:

1) Figure 1 showing the electronics layout and key components used for conducting pulse-shape discrimination.

2) Figures 2 showing energy spectra with and without pulse shape discrimination for a variety of situations.

3) Figures 3 showing the time spectra of sonoluminescence (SL), pulse neutron generator (PNG) neutron emission, and time spectra of counts (via. blocking of counts from the PNG for the first 24 μs) for chilled C_3H_6O and C_3D_6O with and without cavitation. Information is provided on the change in counts with cavitation, clearly showing the statistically significant increase in counts with cavitation during the time span corresponding with bubble implosion. The influence of liquid temperature on nuclear counts emission is also presented clearly showing the close to total elimination of emissions during SL for C_3D_6O at 20^oC.

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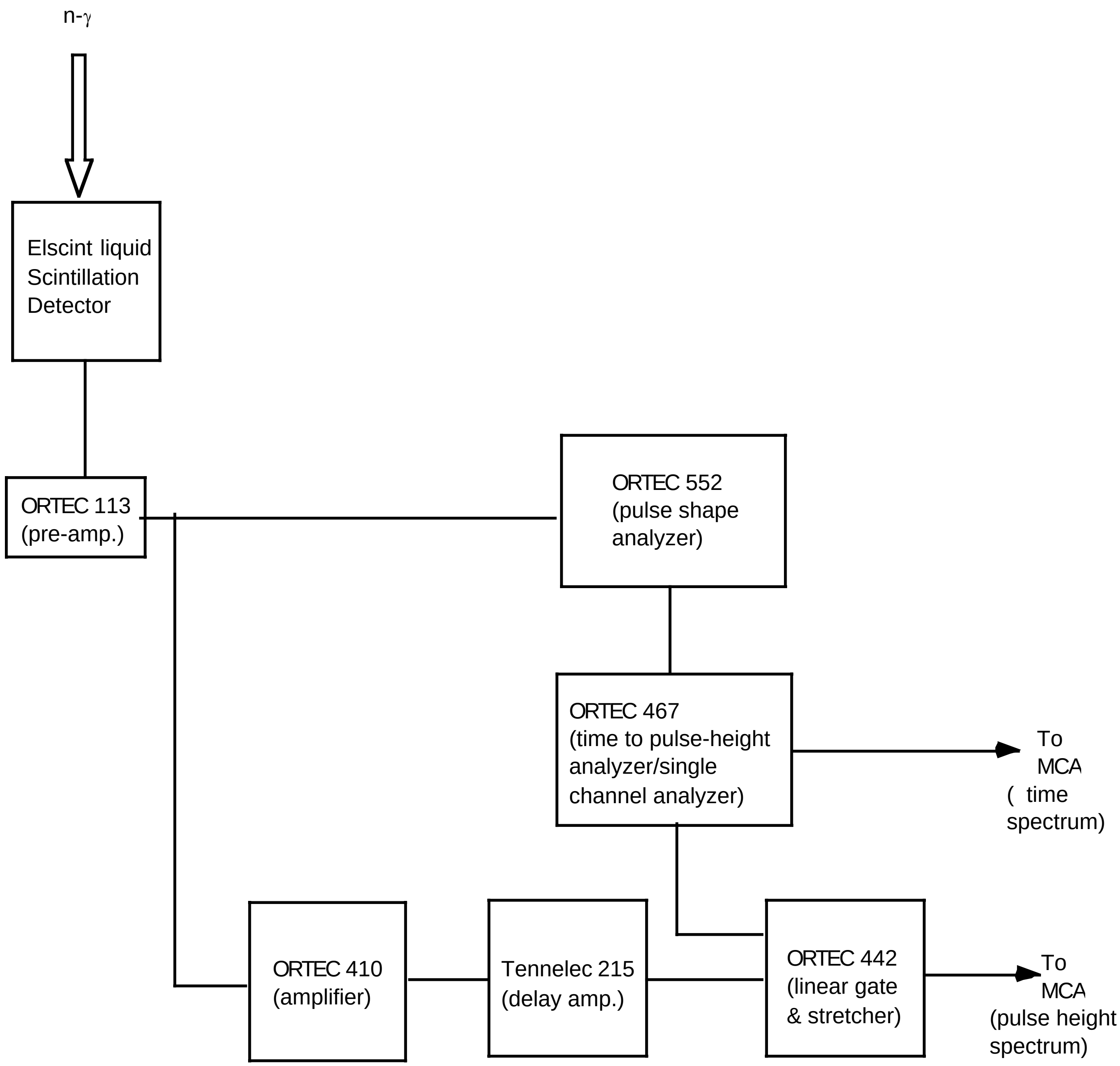

Figure 1. Pulse shape discrimination apparatus

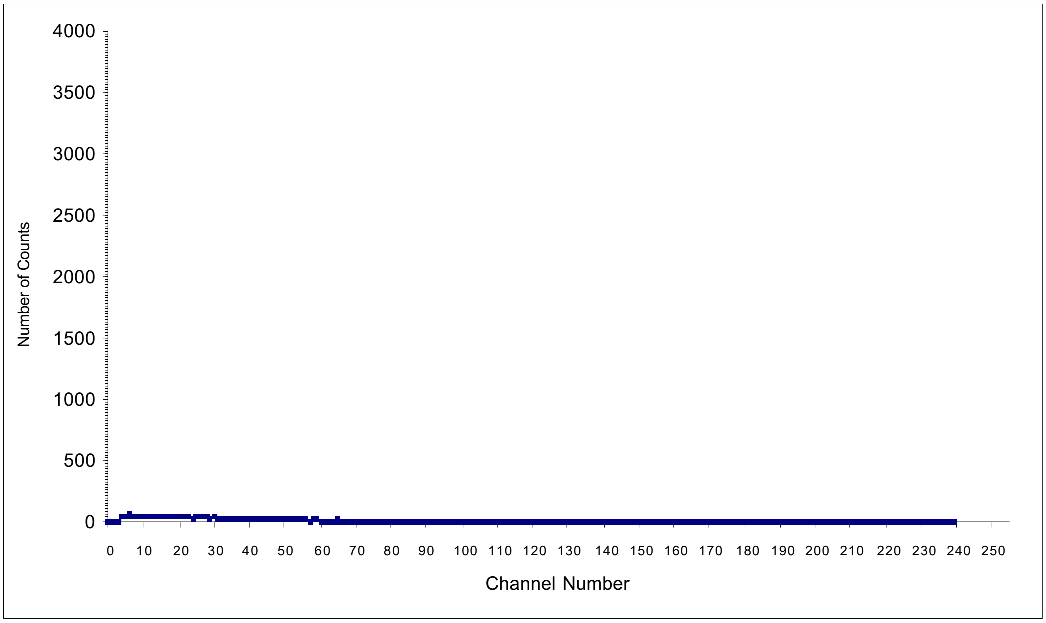

Figure 2.1 (a) Background without Pulse Shape Discrimination (PSD). Without PSD gamma rays as well as neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy).

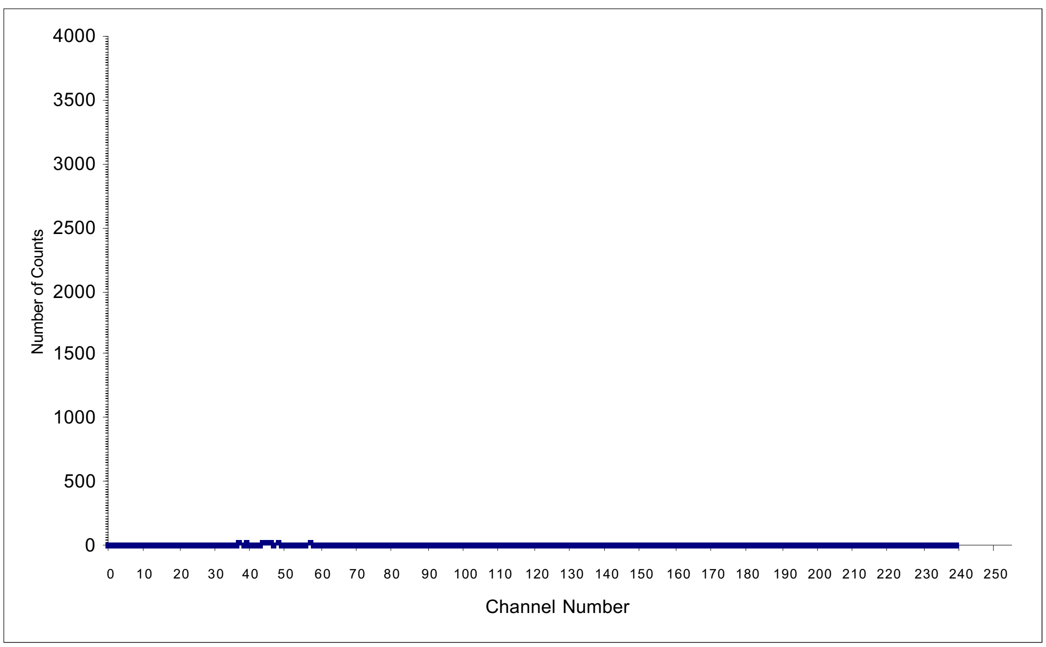

Figure 2.1 (b) Background with Pulse Shape Discrimination (PSD). With PSD gamma rays as blocked off and only neutrons are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy).

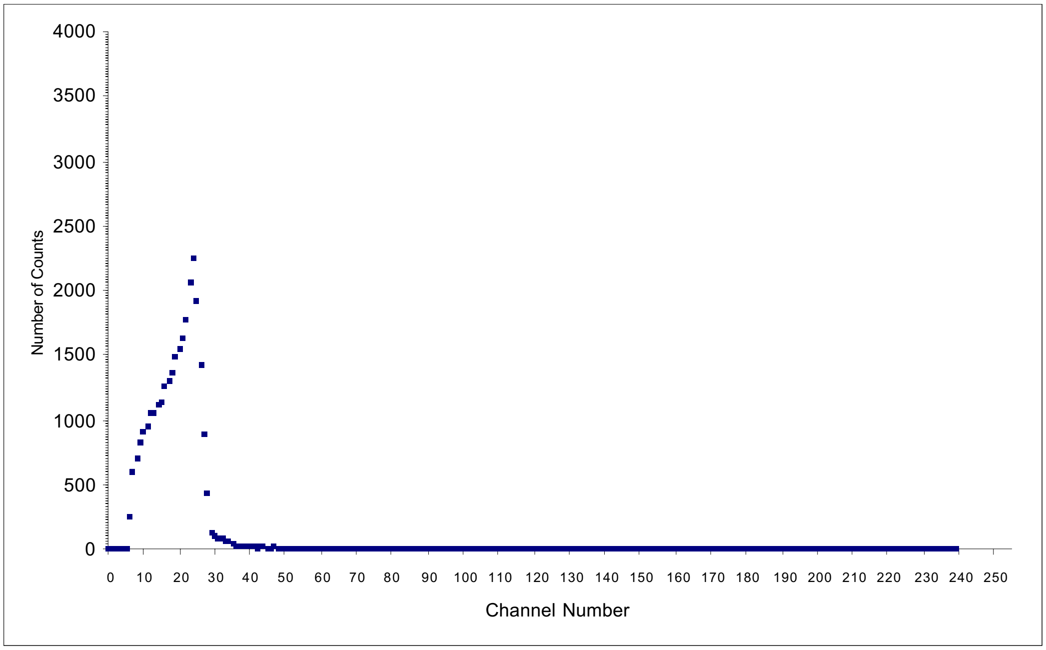

Figure 2.2 (a) Cs 137 Energy Spectrum without Pulse Shape Discrimination (PSD). Cs 137 is a gamma ray emitter. Without PSD gamma rays as well as neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy). Since PSD is not turned on, this plot shows counts received from the gamma rays emitted from Cs 137 as well as from background neutrons that exist in the laboratory.

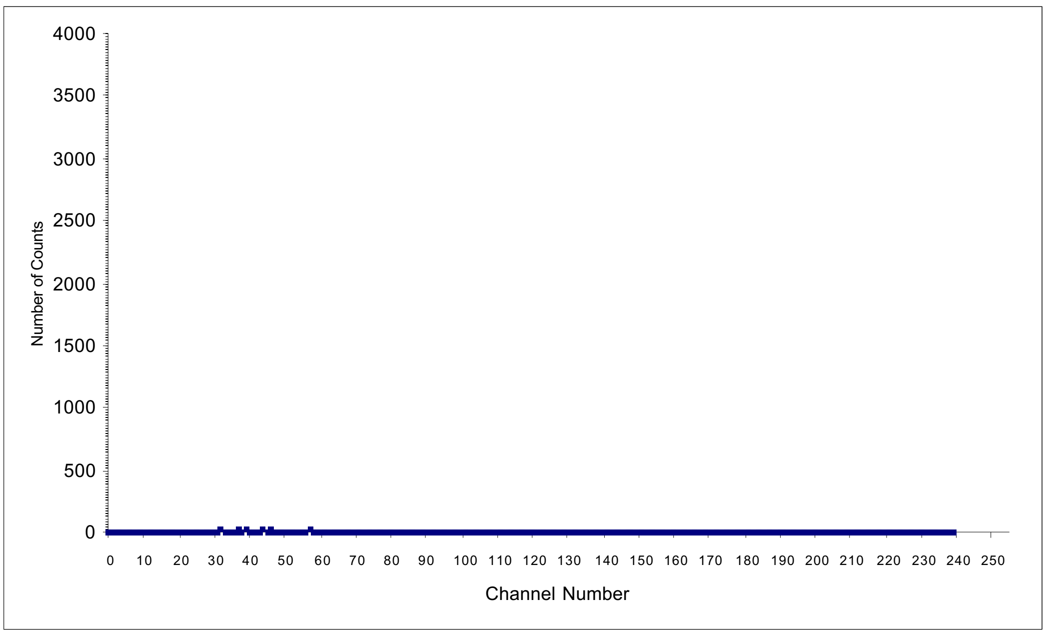

Figure 2.2 (b) Cs137 Energy Spectrum with Pulse Shape Discrimination (PSD) (Note: ~99% of gamma rays are eliminated). With PSD gamma rays are eliminated and only neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy). Since PSD is turned on, the gamma rays from Cs 137 are not counted; this plot shows counts from background neutrons that exist in the laboratory.

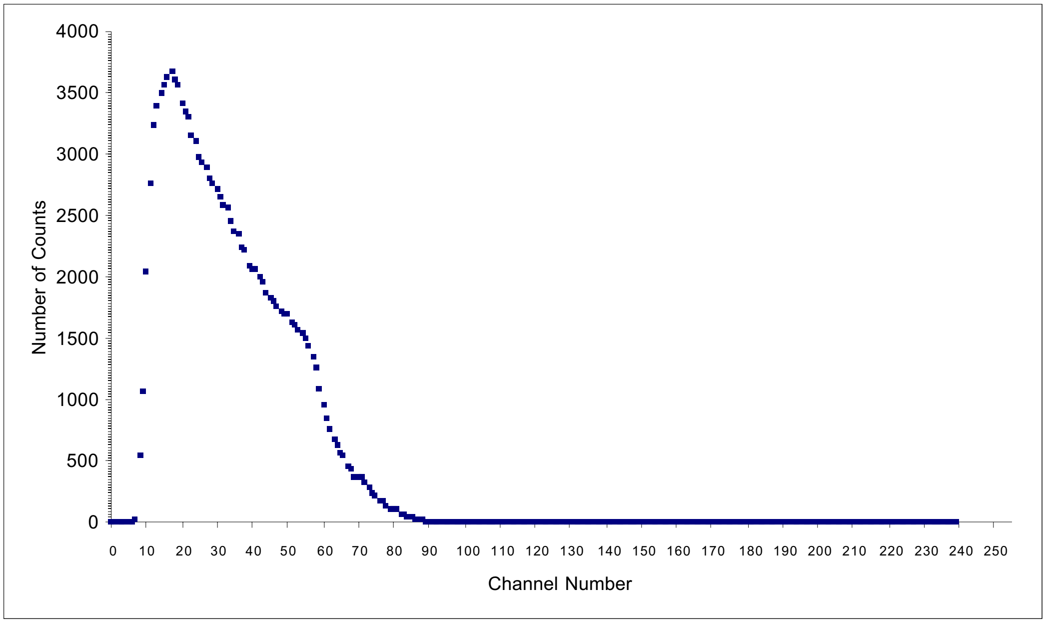

Figure 2.3 (a) Plutonium-Berrylium (Pu-Be) Isotope Source Energy Spectrum without Pulse Shape Discrimination (PSD). A Pu-Be isotope source emits both neutrons of various energies and gamma rays. Without PSD gamma rays as well as neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy). Since PSD is not turned on, this plot shows counts received from the neutrons and gamma rays emitted from the Pu-Be source as well as from background neutrons that exist in the laboratory. This particular source emitted ~2x10^{6} neutrons/s. Pu-Be sources emit about as many neutrons as gamma rays.

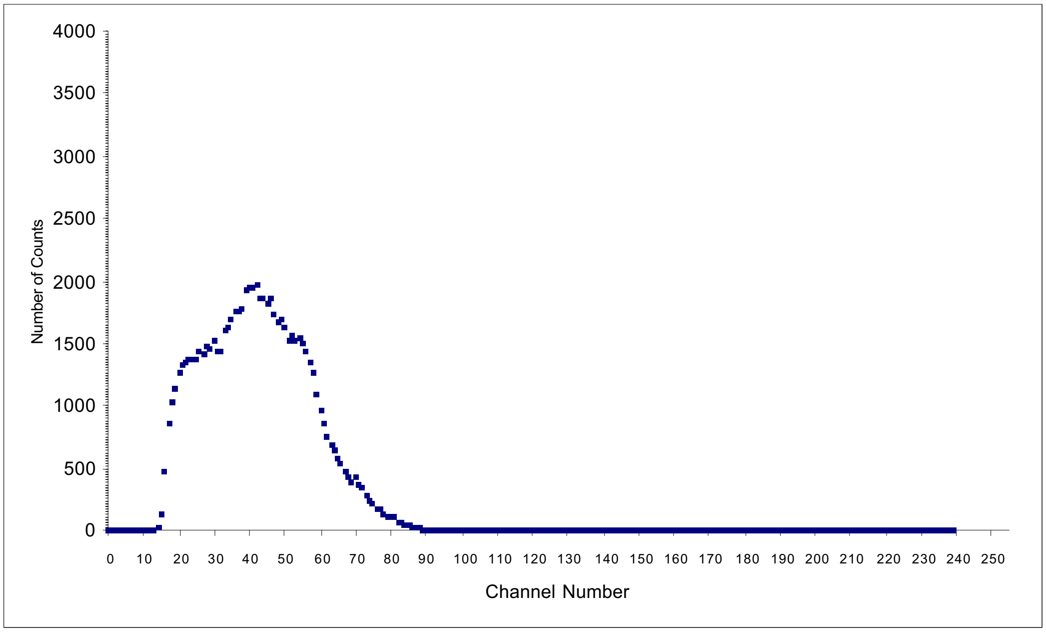

Figure 2.3 (b) Plutonium-Berrylium (Pu-Be) Isotope Source Energy Spectrum with Pulse Shape Discrimination (PSD). A Pu-Be isotope source emits both neutrons of various energies and gamma rays. Without PSD gamma rays as well as neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy). Since PSD is turned on, this plot shows counts received mostly from the neutrons emitted from the Pu-Be source. This particular source emitted ~2×10^6 neutrons/s. Pu-Be sources emit about as many neutrons as gamma rays. This is what we find by comparing the total number of counts collected from Figure 2.3(b) for neutrons alone with the total number of counts collected from Figure 2.3(a) for neutrons and gamma rays. It is to be noted that, due to the need for discriminating against gamma rays and the need to avoid noise signals, the plot above shows no counts below channel number ~15-20. This implies a significant loss of counts for 2.5 MeV neutrons; therefore, the counting efficiency for which will be much lower than for higher energy neutrons.

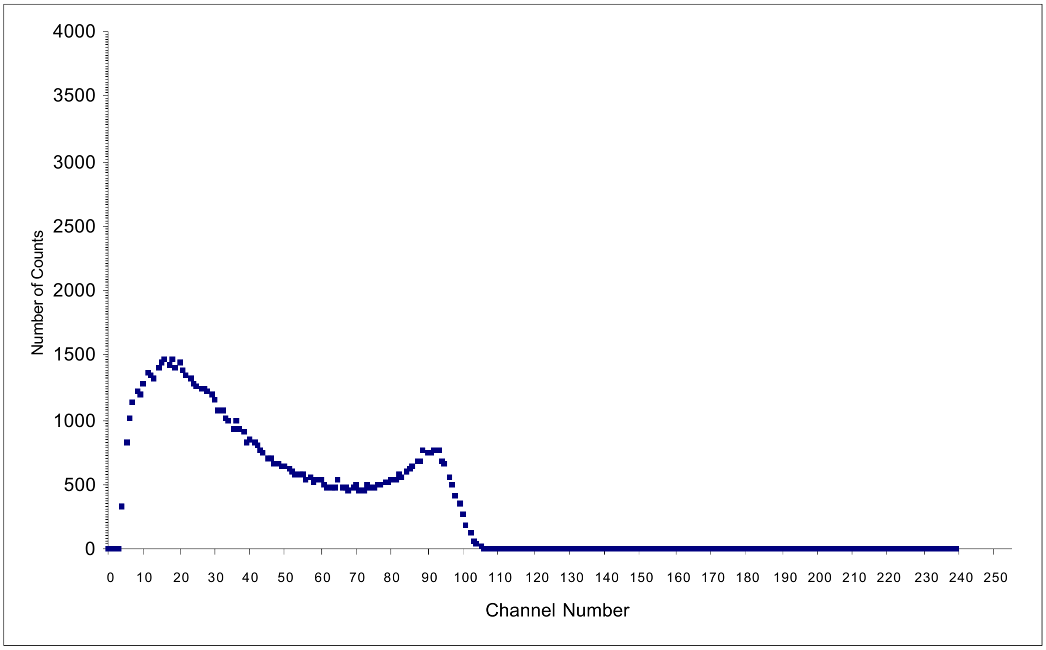

Figure 2.4 (a) Pulse Neutron Generator (PNG) Energy Spectrum without Pulse Shape Discrimination (PSD). This PNG source emits monoenergetic 14 MeV neutrons. Without PSD gamma rays as well as neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy). Since PSD is not turned on, this plot shows counts received from the PNG neutrons and gamma rays emitted from the interaction of these neutrons with materials like acetone,etc. and background neutrons that exist in the laboratory. At the settings used, this PNG source emitted ~$1x10^6$ neutrons/s.

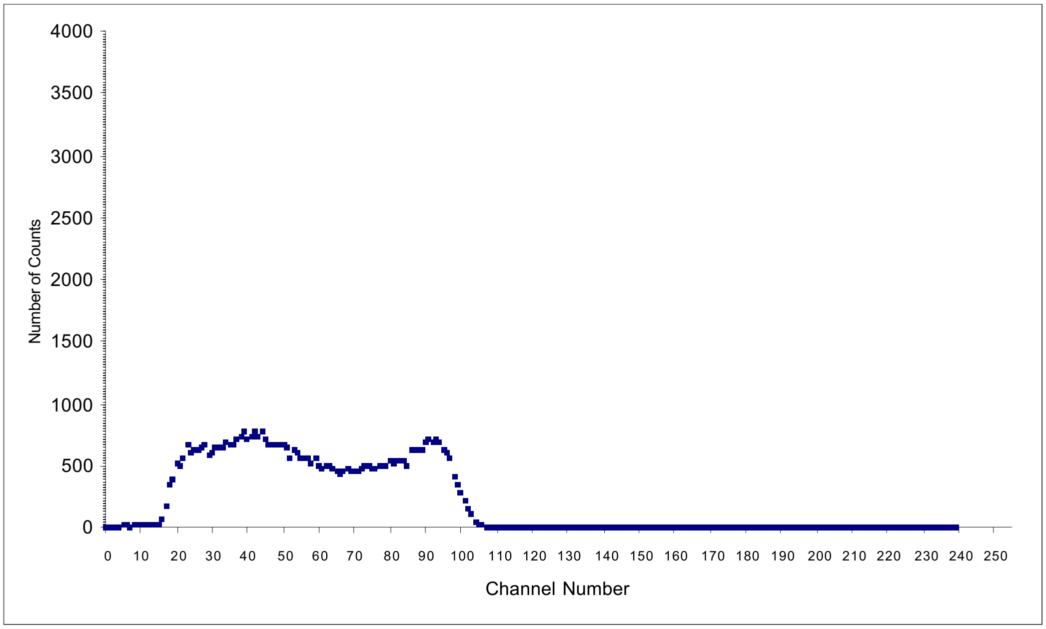

Figure 2.4 (b) Pulse Neutron Generator (PNG) Energy Spectrum with Pulse Shape Discrimination (PSD). This PNG source emits monoenergetic 14 MeV neutrons. With PSD gamma ray are eliminated and only neutrons of various energies are counted. The x-axis denoting channel number is an indication of how energetic the interaction of a gamma ray or neutron is when they impinge upon the scintillation material in the nuclear scintillation counter (i.e., higher the channel number greater is the energy). Since PSD is turned on, this plot shows mostly counts received from the PNG neutrons and relatively minimal background neutrons that exist in the laboratory. At the settings used, this PNG source emitted ~$1x10^6$ neutrons/s. Comparing the counts collected with PSD from counts collected without PSD we find for our system that the gamma ray-to-neutron ratio is roughly equal. It is to be noted that, due to the need for discriminating against gamma rays and the need to avoid noise signals at lower energy levels, the plot above shows no counts below channel number ~15-20. This implies a significant loss of counts for 2.5 MeV neutrons; therefore, the counting efficiency for 2.5 MeV neutrons will be much lower than for 14 MeV neutrons.

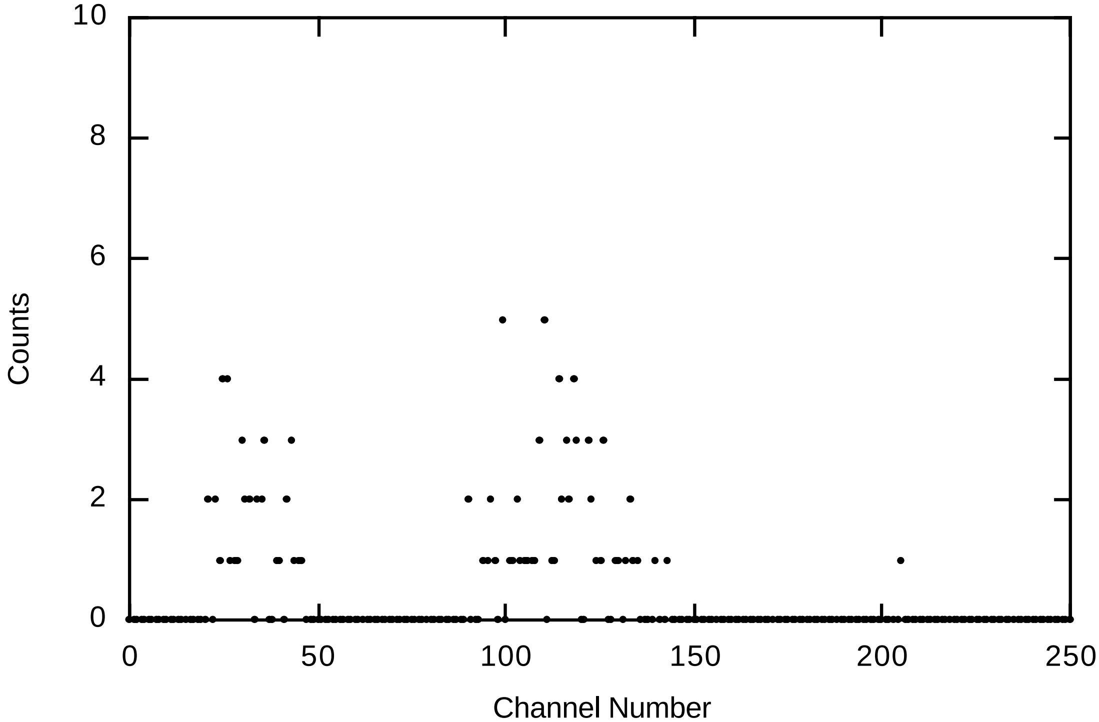

Figure 3 (a) PMT SL Time Spectrum (C_3D_6O) - Note: About 37% of SL counts fall within time of PNG operation; the remaining 70% are seen to occur about 27-30 μs later.

Notes: (1) Spectrum start with start of TTL pulse to pulsed-neutron generator
(2) Each channel corresponds to 0.4 microseconds
(3) Photomultiplier high voltage set at –450V accounts for false SL signals during PNG firing (such signals absent for –300V settting); PNG operated at 10^6 n/s and 200 Hz.

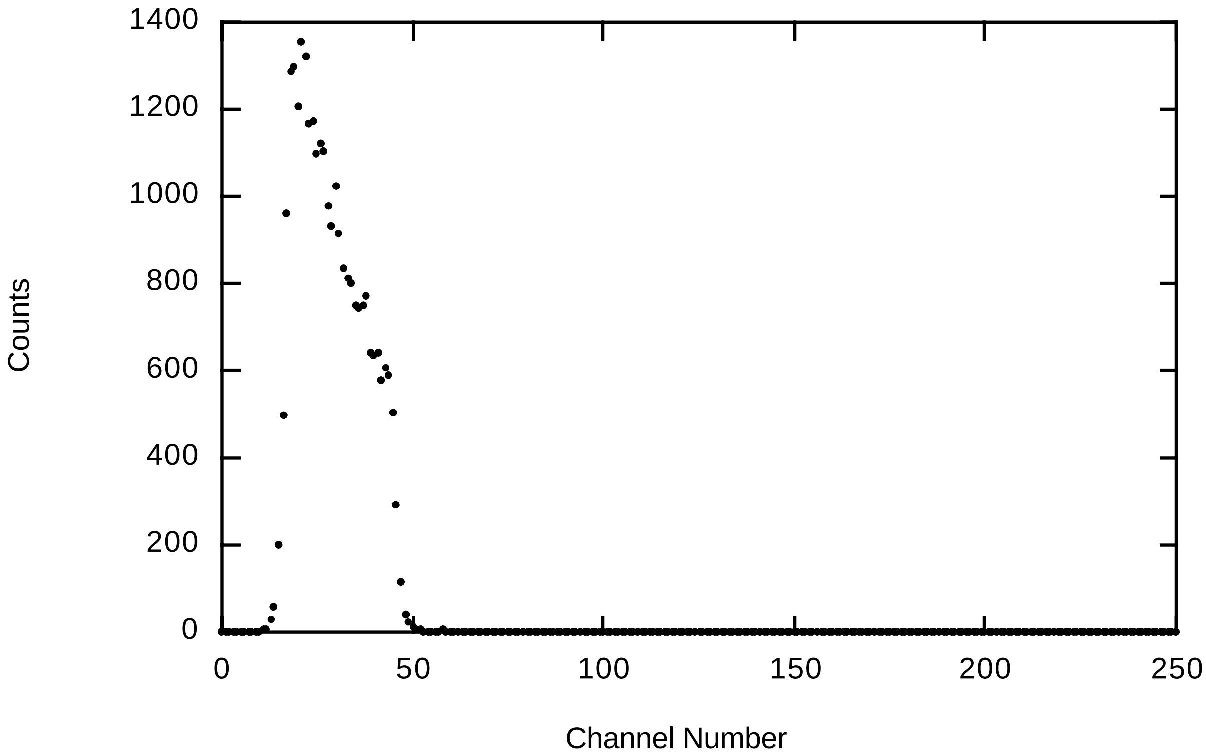

Figure 3 (b) Pulse Neutron Generator Time Spectrum

Notes: (1) Spectrum start with start of TTL pulse to pulsed-neutron generator
(2) Each channel corresponds to 0.4 microseconds

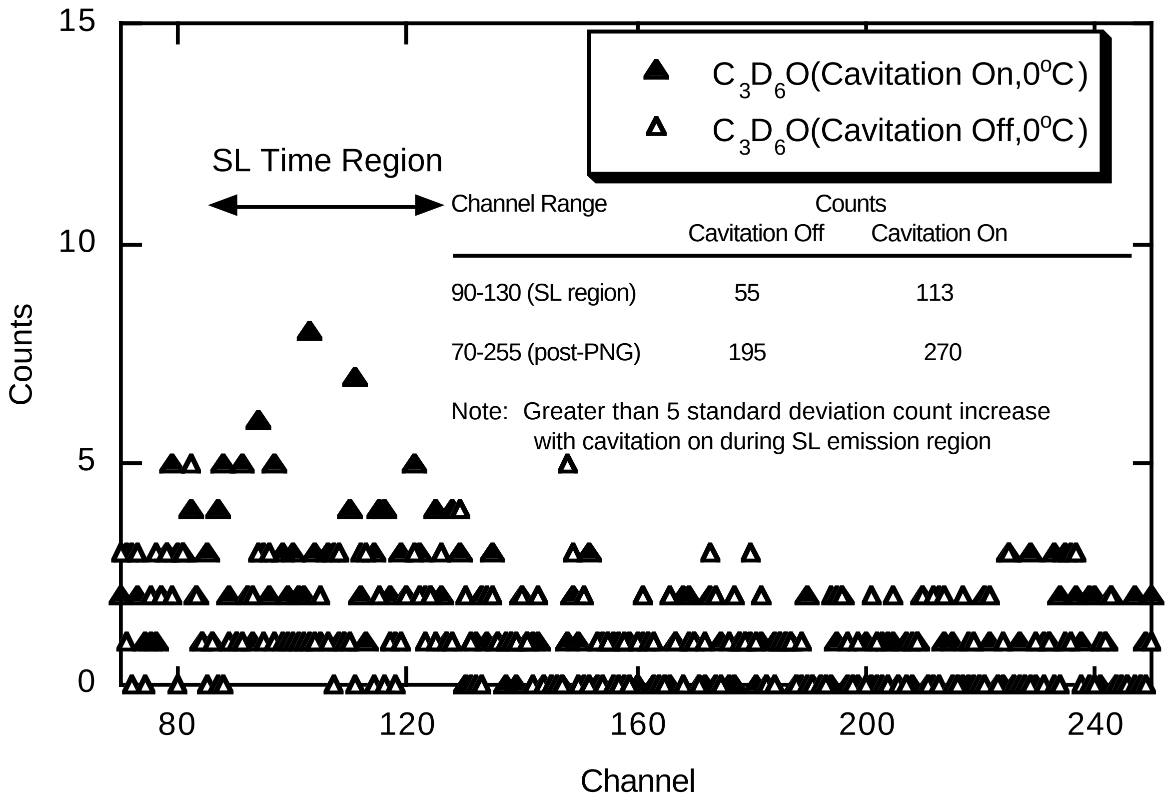

Figure 3c. Time spectrum of counts with and without cavitation for C_3D_6O (0^oC) in region of SL bubble implosion (see Figure 3a) and beyond.
Notes:
(1) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.
(2) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.

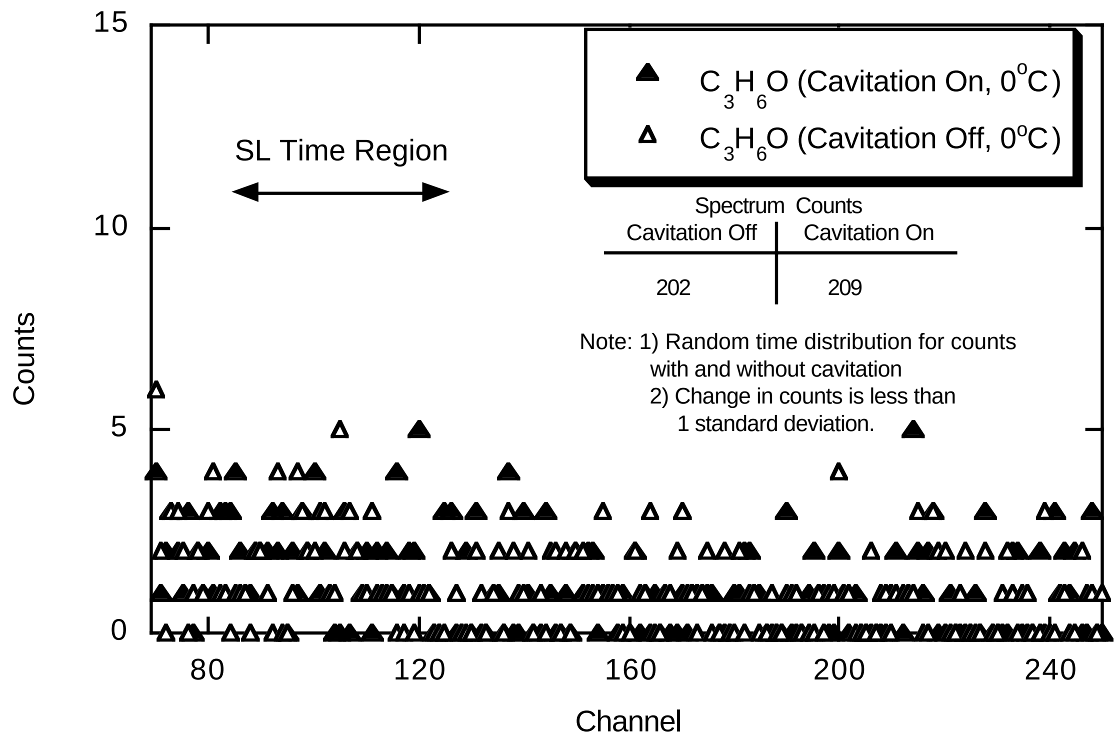

Figure 3d. Time spectrum of counts with and without cavitation for C_3H_6O (0^oC) in region of SL bubble implosion (see Figure 3a) and beyond.

Notes:

(1) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.

(2) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz..

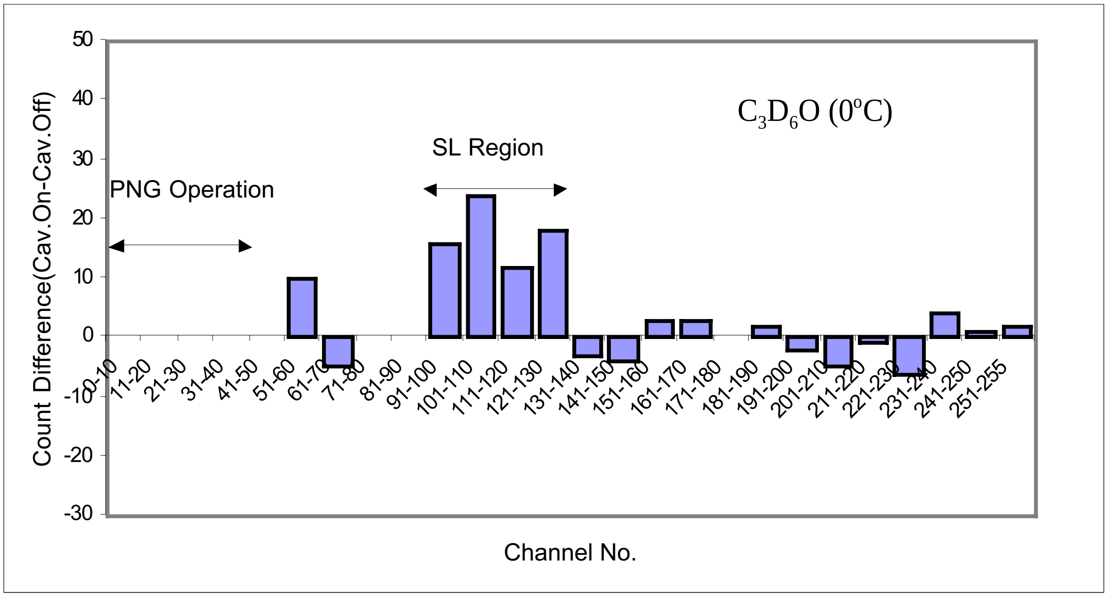

Figure 3e. Averaged (~4 μs) time spectrum of counts difference between cavitation on and cavitation off for C_3D_6O (0°C) in region of SL bubble implosion (see Fig. 3a) & beyond.

Notes:

(1) Time averaged counts (averaging over 10 channels = ~4 μs)

(2) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.

(3) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.

(4) The counts in the SL region are about 1% of the counts obtained during PNG operation. However, since the efficiency of detection of 2.5 MeV neutrons is found to be about 10-100 times lower than for 14 MeV neutrons, the emission rate during SL is estimated within uncertainties to be comparable in magnitude (within a factor of 5 to 10) to that during PNG operation.

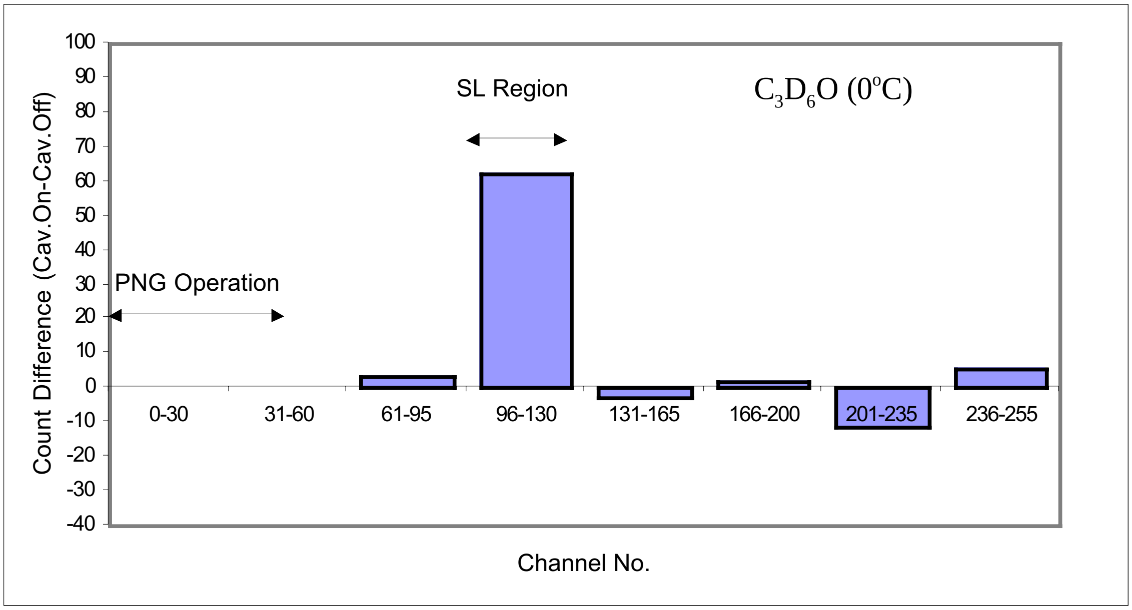

Figure 3f. Averaged (~14 μs) time spectrum of counts difference between cavitation on and cavitation off for C_3D_6O (0°C) in region of SL bubble implosion (see Fig. 3a) & beyond.

Notes:

(1) Time averaged counts (averaging over 35 channels = ~14 μs)

(2) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.

(3) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.

(4) The counts in the SL region are about 1% of the counts obtained during PNG operation. However, since the efficiency of detection of 2.5 MeV neutrons is found to be about 10-100 times lower than for 14 MeV neutrons, the emission rate during SL is estimated within uncertainties to be comparable in magnitude (within a factor of 5 to 10) to that during PNG operation.

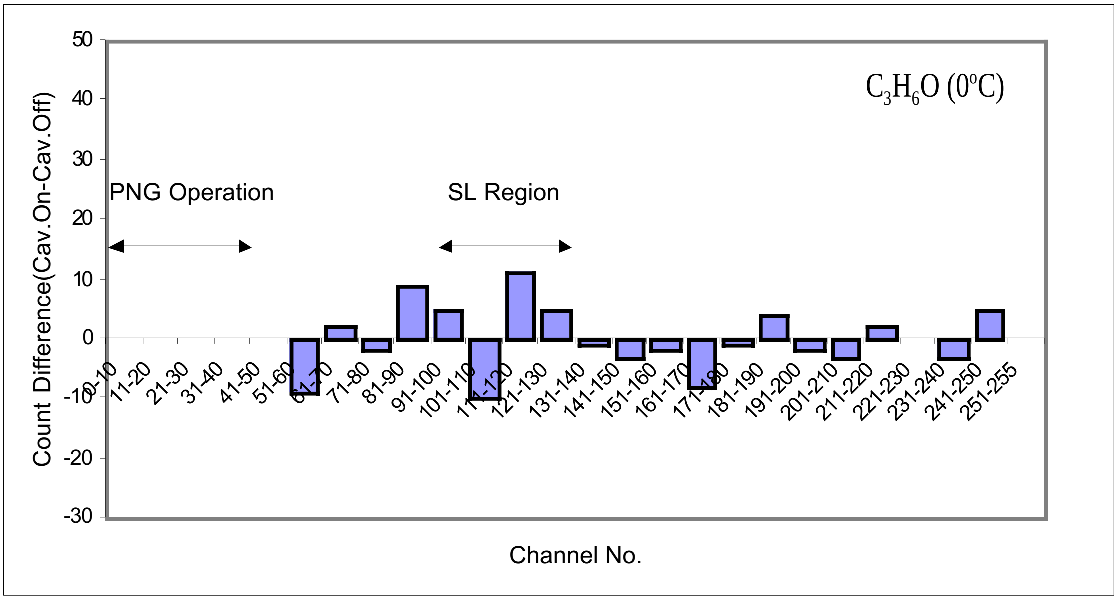

Figure 3g. Averaged (~4 μs) time spectrum of counts difference between cavitation on and cavitation off for C_3H_6O (0°C) in region of SL bubble implosion (see Fig. 3a) & beyond.

Notes:

(1) Time averaged counts (averaging over 10 channels = ~4 μs)

(2) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.

(3) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.

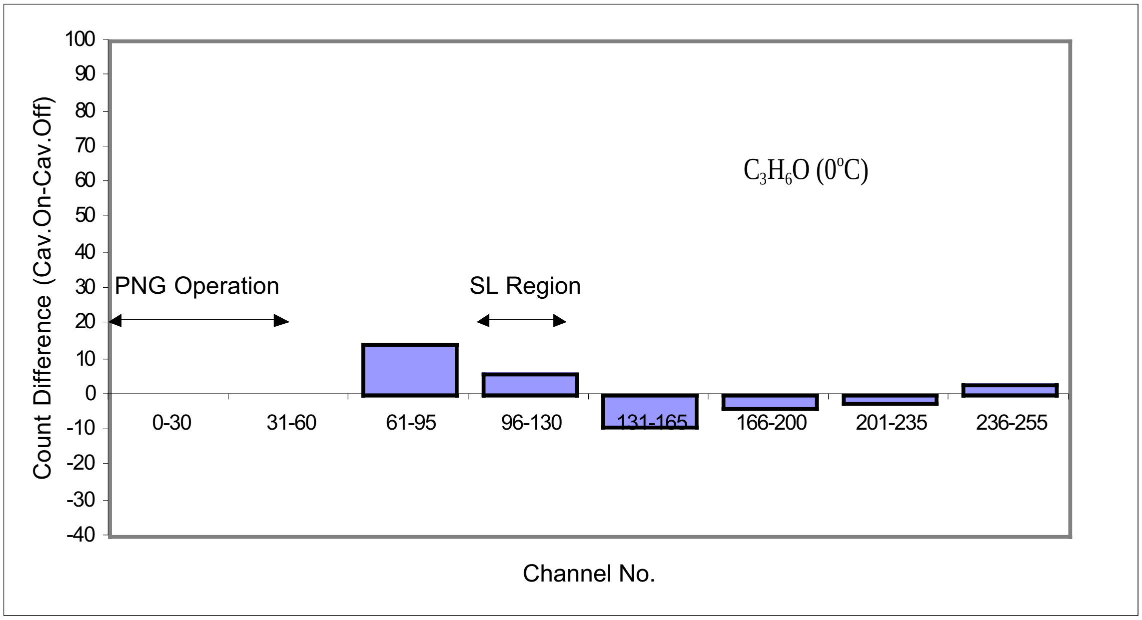

Figure 3h. Averaged (~14 μs) time spectrum of counts difference between cavitation on and cavitation off for C_3H_6O (0^oC) in region of SL bubble implosion (see Fig. 3a) & beyond.

Notes:

(1) Time averaged counts (averaging over 35 channels = ~14 μs)

(2) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG)

(3) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.

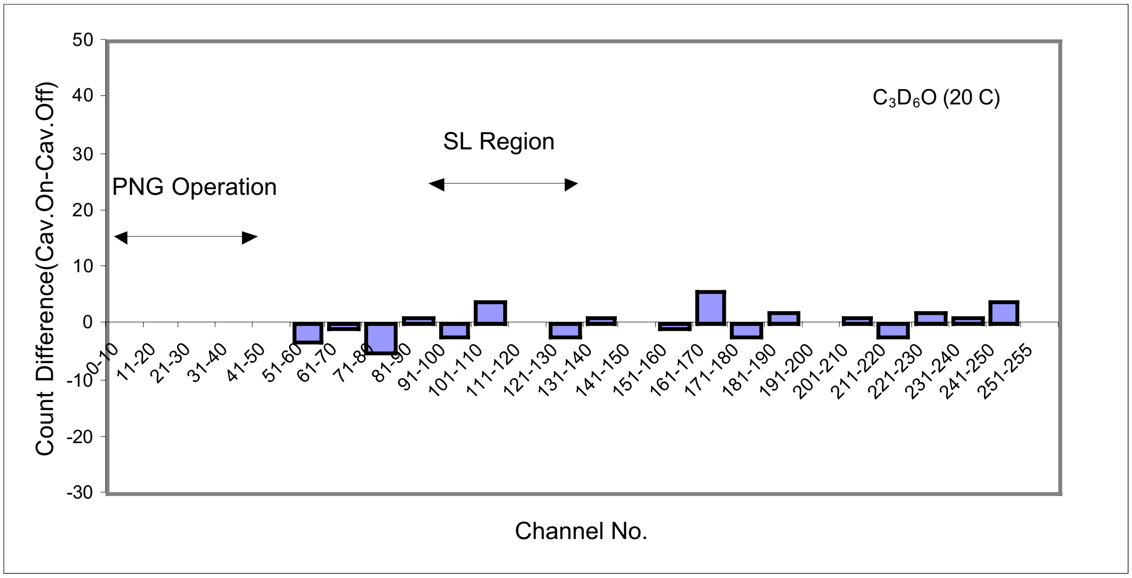

Figure 3i. Averaged (~4 μs) time spectrum of counts difference between cavitation on and cavitation off for C_3D_6O (20°C) in region of SL bubble implosion & beyond.

Notes:

(1) Time averaged counts (averaging over 35 channels = ~14 μs)

(2) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.

(3) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.

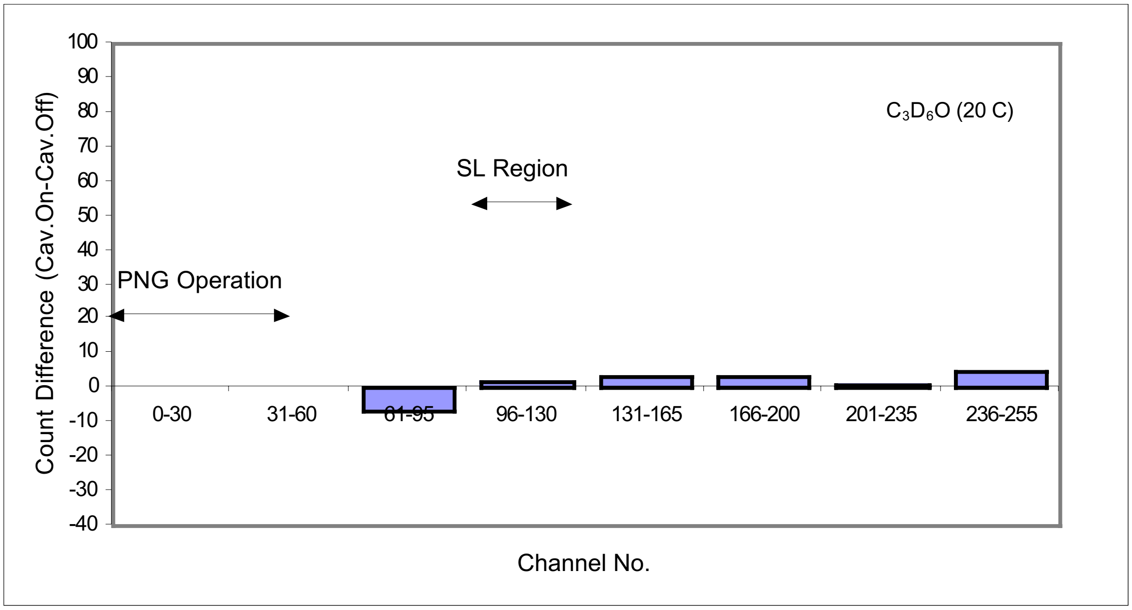

Figure 3j. Averaged (~14 μs) time spectrum of counts difference between cavitation on and cavitation off for C_3D_6O (20°C) in region of SL bubble implosion & beyond.

Notes:

(1) Time averaged counts (averaging over 35 channels = ~14 μs)

(2) Spectrum start with start of TTL pulse to pulsed-neutron generator (PNG); PNG neutron emission begins at channel 15.

(3) Each channel corresponds to 0.4 microseconds; PNG operated at 200 Hz.