Appendix I – Additional Evidence to Purdue University C-22 Review Committee

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Additional Evidence to Purdue University C-22 Review Committee

by

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August, 2007

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Executive Summary

This transmittal provides evidence to address and resolve three important technical issues brought up by various individuals over the past two years (including Reviewer D of the C-22 Committee).

A primary concern brought up earlier in 2006 was that our published neutron spectrum appeared inconsistent with that calculated by University of California at Los Angeles (UCLA) for a D-D bubble nuclear fusion event. The UCLA calculation neglected to include the ~ 1" (3cm) of intervening ice-pack wall shielding surrounding the test cell for the experiments reported in the 1/2006 PRL article by Taleyarkhan et al. Upon including the ice-pack shielding and using not one, but two, independent Monte-Carlo based methods to cross-check each other we find that the calculated spectra are indeed consistent with and match our published bubble nuclear fusion spectra. Furthermore, the predictions for neutron spectra without ice-pack shielding closely match the independent bubble fusion neutron spectrum later measured and reported by Forringer et al. (2006) where intervening ice-pack shielding was absent. These findings and resolutions should go a long way towards conclusively settling the immense controversy generated by the 3/8/2006 Nature article. It is ironic that so much controversy has resulted from the simple failure to include an inch of water.

A second question brought up in the literature and also by Reviewer D asks "What is the source of counts in our published neutron spectra above the 2.45 MeV Proton-Recoil-Edge (PRE)?" A separate section is devoted to answering this question. It shows that excess counts above the PRE should indeed be present during bubble fusion experiments. The main contributing phenomena are neutron pileup, imperfect detector resolution and gamma photon leakage. Experiments with pulsed neutrons from a D-T nuclear fusion neutron generator were conducted at rates comparable to expected rates from bubble fusion implosion events. The predictions of the super compression theory paper published in the journal *Phys. of Fluids* (Nigmatulin et al., 2005) appear consistent with experimental data. These experiments and theoretical analyses confirm that significant excess counts above the 2.45 MeV PRE channel should be expected for bubble fusion experiments of the type reported earlier by our group.

We have also taken note of questions posed by Reviewer D in relation to distortions of the pulse-shape-discrimination (PSD) time spectra for the limited scoping experiments conducted on 9.19.03 in Purdue's G60 Pharmacy laboratory by Oak Ridge National Laboratory (ORNL) staff. Evidence is provided for the cause of the distortions in the PSD spectra and for customary determination of the acceptance windows for valid neutron and gamma emission counts under such conditions. By direct comparison of PSD time spectra from a D-T nuclear fusion neutron generator, it is then shown that the excess neutron and gamma counts fall within what would customarily be considered valid (neutron-gamma) acceptance windows. Furthermore, the ratio of neutron-to-gamma counts for the 9.19.03 experiments is shown to be similar to the direct experimentally derived values from an accelerator-based nuclear fusion neutron source. Additional data taken by ORNL staff for the energy spectrum of excess counts is also provided to show excess neutron emissions mostly occur in the ≤ 2.45 MeV neutron energy window. These self-initiated efforts should be a confirmation of the willingness of Dr. Taleyarkhan and his team members to positively accept valid, professionally-offered criticism and then to work diligently to address them in as expeditious manner as possible.

This evidence package was prepared as a team effort with technical assistance from Professor Robert C. Block of Rensselaer Polytechnic Institute (RPI), along with Dr. Y. Xu and Joe Lapinskas of Purdue University. Prof. Block was a co-author of Taleyarkhan's 2002, 2004 and 2006 publications on sonofusion and herein, provided his insights, data analyses, review and feedback on nuclear instrumentation aspects as applied to sonofusion experimentation. Dr. Xu was co-author of Taleyarkhan's 2006 *Phys. Rev. Ltrs.* publication. For the present transmittal he offered assistance in terms of conducting additional calibration experiments and for assessing neutron pileup potential during pulsed events with a D-T fusion neutron accelerator source compared with random emissions from a Pu-Be isotope source. Joe Lapinskas, a graduate student in the School of Nuclear Engineering conducted the Monte-Carlo nuclear particle transport calculations reported herein along with Dr. Xu, for addressing neutron spectra related measurements using NE-213 detectors in sonofusion studies with and without ice-pack shielding. Dr. J. Cho (previously of ORNL, and presently in S. Korea) has collaborated all along and his contributions and assistance are acknowledged.

1. Bubble fusion neutron emission spectra with and without intervening ice-pack shielding.

Allegations have been made that the published measured bubble fusion neutron spectrum (Figure 4 of the Phys. Rev. Ltrs. Publication by Taleyarkhan et al., 2006) obtained with a 5cm x 5cm liquid scintillation (LS) detector does not compare well with that predicted via computer code calculations (Naranjo, 2006) from University of California at Los Angeles (UCLA). Unfortunately, the predictions from UCLA did not account for the ~3cm thick ice-pack cum plastic sheet shielding between the test cell enclosure and the LS detector.

In order to evaluate the relative effects on the expected 2.45 MeV spectrum with and without ice-pack shielding we conducted assessments with two independent methods to obtain cross-checks and better confidence for the validity of our predictions. The first approach was to establish a simulation platform similar to that used by UCLA. The second approach was based on directly combining neutron emission spectra emanating from the experiment system with the published (measured) neutron energy spectra for a 5cm x 5cm sized NE-213 detector [viz., same as what was used by Taleyarkhan et al.(2006)]..

Approach 1: MCNP5-SCINFUL (Combination numerical simulation platform for neutron spectrum-cum-detector response)

We developed our own combination (i.e., neutron spectrum and detector response) Monte-Carlo simulation capability using well-established computer codes developed by the U.S. Department of Energy (DOE) over the past 40 years. In the first step, the transport characteristics of a 2.45 MeV neutron through ~4cm of test cell liquid followed by the quartz enclosure were computed using the well-known MCNP5 nuclear transport code developed by the Los Alamos National Laboratory (LANL, 2003). For the present purpose, this modeling was performed in a 1-D spherical coordinates system which is considered a reasonably good first approximation (because of the test cell central volume-fusion bubble region is subtended in a somewhat spherical fashion by the glass walls to the sides and to the top and bottom glass reflectors in the vertical direction in a somewhat proportional fashion. The emitted neutrons from the enclosure were further subjected to 3cm of water shielding and the spectrum once again calculated. Fig. 1A depicts the neutron energy spectrum in terms of fraction of the total at the boundary of the test cell glass surface and at the outside surface of the 3cm thick ice-packs. It is readily seen that the original 2.45 MeV neutron will experience significant down scattering resulting in a range of neutron energies down to thermal energy levels. The extent of down scattering is enhanced significantly with the addition of 3cm of water (ice-pack) shielding.

The resulting neutron spectrum was then used in conjunction with the USDOE's Scintillator Full (SCINFUL) Response neutron detection code (Dickens, 1988) precisely for modeling the response of NE-213 LS detectors to obtain the emanating light pulse height response spectrum. SCINFUL models neutron interaction within the NE-213 using Monte-Carlo methodology and provides the spectrum shape that would be measured to the proton-recoil-edge (PRE) but does not account for the effect of imperfect detector resolution which can vary from detector to detector depending on numerous factors such as light collection, age of detector, etc. Nevertheless, the combined MCNP5-SCINFUL code system offers an excellent tool for predicting the expected pulse-height spectrum for our experiments.

Results were obtained for the distribution of neutron energies for a 2.45 MeV neutron traversing from within the test cell and emanating out of the quartz surface followed with down scattering further in 3cm of ice-pack material (modeled as water). The predicted neutron spectra are shown in Fig. 1A. As clearly seen from Fig. 1A, the 2.45 MeV neutron will experience very significant down-scattering during transport through the test cell (open triangle) and even more through the ice-pack (solid triangle) shielding.

The emitted neutron emission spectra of Fig. 1A were utilized as inputs into the SCINFUL code to then provide an estimate of the spectral shapes with and without ice-pack shielding. Fig. 1B shows the predicted light output pulse-height from the 5cm x 5cm LS detector. One clearly notices that the spectrum with ice-pack shielding is radically different from the spectrum without ice-pack shielding and underscores the fundamental importance of including shielding materials.

Whereas, the spectrum with ice-pack appears qualitatively similar to that measured by Taleyarkhan et al. as published in Fig. 4 (Taleyarkhan et al., 2006), the calculated light output pulse-height spectrum without ice-pack shielding approximates the general characteristics of the spectrum measured by Forringer et al. (2006) and also to the UCLA spectrum (Naranjo, 2006) where the ice-pack material was absent.

A more comprehensive comparison of data and predictions is provided later in this section.

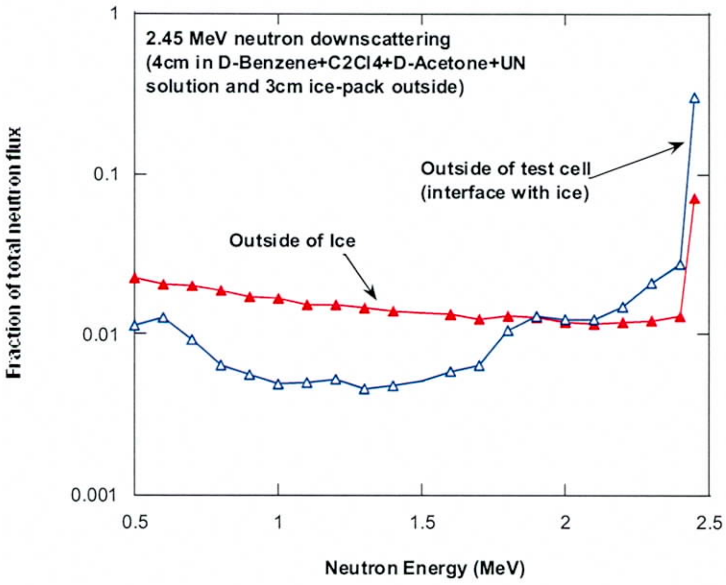

Fig. 1A. MCNP5 computed neutron energy distribution for 2.45 MeV neutron after transport through 4cm of test cell contents and then through 3cm of ice-pack (modeled as water).

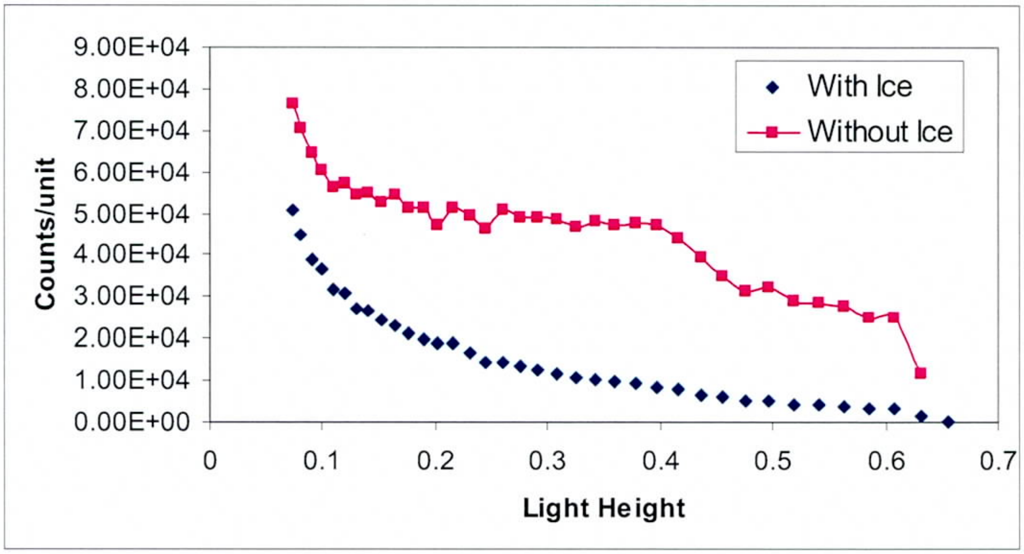

Fig. 1B Monte-Carlo simulation (SCINFUL-MCNP5) prediction of counts vs light-output (pulse-height) for bubble fusion neutron spectra of Fig. 1A with and without ice-pack shielding.

Approach 2: MCNP5-NE213 (MCNP5 Neutron Spectrum combined piece-wise with measured NE-213 detector spectra at various energies)

A second approach was developed to independently compare against the predictions of the MCNP5-SCINFUL code predictions. This was considered useful for two main reasons. First, to evaluate if SCINFUL code predictions were in line with expectations for spectrum shape below the 2.45 MeV PRE. The second reason was to assess how far above the 2.45 MeV PRE one should expect counts due to imperfect detector resolution around the PRE, a well-known effect (e.g., Dickens, 1983; Lee, 1998) and also highlighted in established text-books on the subject (Knolls, 1989). Fortunately, a very relevant study was recently reported in the reputable journal *Nucl. Instr. Methods in Phys. Research* (Lee and Lee, 1998) in which the authors used a 5cm x 5cm NE-213 detector identical in size to the one used in the Taleyarkhan et al. (2006) study. Lee and Lee provide individual pulse-height spectra for various neutron energies ranging from 0.5 MeV to 2.5 MeV. Their results of the measured spectra are reproduced in Fig. 1C.

The MCNP5 neutron spectrum variation with energy was broken down in the six energy groups of Fig. 1C to provide the relative proportion of neutrons in each group. Thereafter, the digitized values of pulse-height spectra of Fig. 1C at each energy were multiplied by the fractional neutron counts in that energy, upon which the individual spectra were combined to obtain an overall composite spectrum. This was performed for the two cases with and without ice-pack shielding.

Results of comparisons

Results from the two approaches were then scaled to the channel gain of the Taleyarkhan et al. (2006) measured neutron spectrum and the various results are shown in Fig. 1D. Fig. 1E includes the Forringer et al. (2006) measurements where intervening ice-pack shielding was absent. We can now make the following observations and conclusions:

i) When ice-pack shielding is taken into account, the MCNP5-SCINFUL as well as the MCNP5-NE213 predictions are consistent with and compare very well with our measured and reported bubble fusion neutron spectrum (Taleyarkhan et al., 2006). This is a major clarification that helps lay to rest the significant consternation, ironically resulting from the mere omission of ~ 1" of water . For this simulation, the Taleyarkhan et al. results at Channel 10 were scaled to equal the predicted value of counts from the MCNP5 based predictions after which the same scale factor was used for all higher channels.

ii) Both MCNP5-SCINFUL and MCNP5-NE213 predictions are consistent with each other below the 2.45 MeV PRE. Above the 2.45 MeV PRE, SCINFUL code predicts zero counts. However, the NE213 detector data of Lee and Lee extend almost 50+ neutron channels above the PRE. This is an indication that real-life detectors can be expected to allow neutron counts to be collected above the PRE channel. This provides at least one independent corroboration for, and a valid reason for the excess counts measured (above the PRE) in the neutron spectrum during bubble fusion experiments (Taleyarkhan et al., 2006).

iii) Without the ~ 1" ice-pack shielding, the UCLA predictions (Naranjo, 2006) are consistent with and similar in magnitude and shape with the MCNP5-SCINFUL and MCNP5-NE213 predictions. The same scale factor used earlier for MCNP5-based simulations at Channel 10 was also used for comparing the predictions without ice-pack shielding. The UCLA predictions (Naranjo, 2006) were offered only for Channel 12 and higher. Therefore, the UCLA prediction at Channel 12 was multiplied by a scale factor to equal the MCNP5-SCINFUL based calculation at Channel 12 and then used for all other UCLA predictions.

iv) The MCNP5-NE213 approach (based on actual measurements) offers results which are intermediate between the MCNP5-SCINFUL and the public-source GEANT code predictions of UCLA. Nevertheless, all three approaches are reasonably close to each other in terms of overall shape and quantity of counts to be expected as a function of light pulse height below the 2.45 MeV PRE.

v) The published bubble fusion neutron spectrum of Forringer et al. (2006) which were obtained without intervening ice-pack shielding is consistent with and compares well with all three prediction schemes. As for the bubble fusion spectrum of Taleyarkhan et al. (2006), the Forringer et al. (2006) measurements also show counts above the 2.45 MeV PRE as also confirmed by using the MCNP5-NE213 method.

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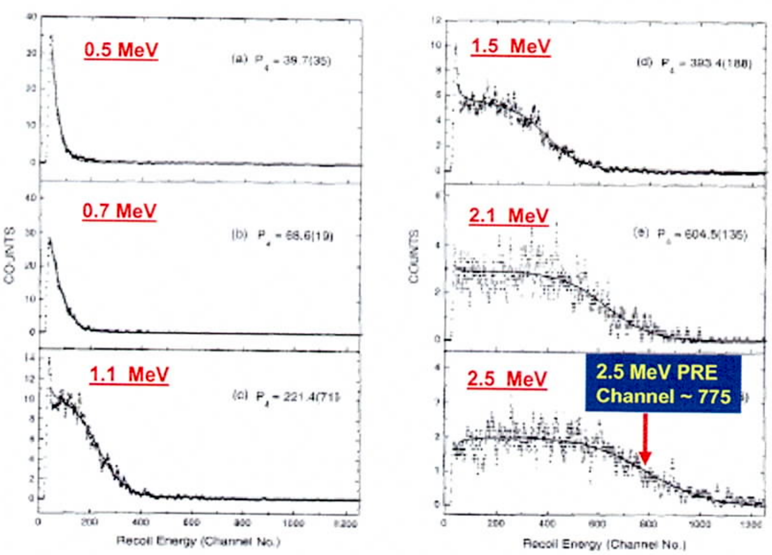

Fig. 4. Proton recoil spectra fitted with a theoretical function explained in the text for maximum proton energies of (a) 0.5, (b) 0.7, (c) 1.1, (d) 1.5, (e) 2.1 and (f) 2.5 MeV. Numbers in parenthesis represent fitting errors in the last significant digits of the P_4 parameter.

Fig. 1C Measured pulse-height spectra in a 5cm x 5cm NE-213 detector(Lee and Lee, 1998) for neutron energies ranging from 0.5 to 2.5 MeV.

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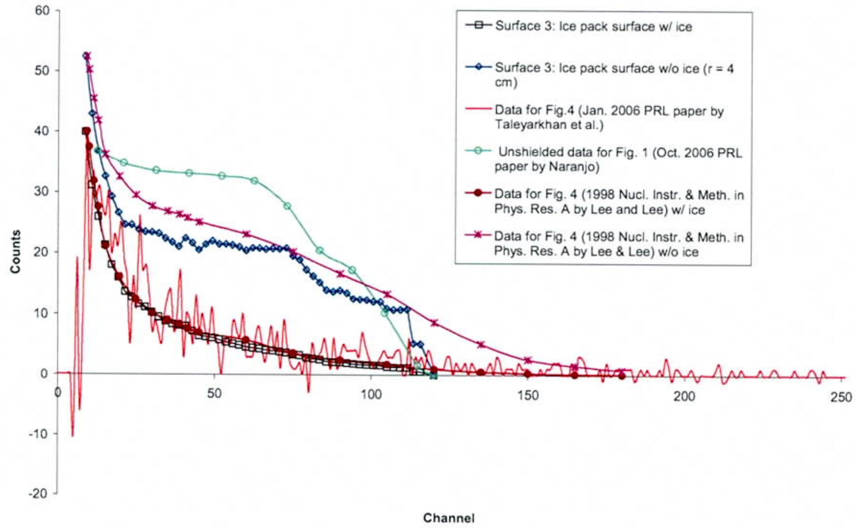

Figure 1D Measured (published) bubble fusion spectra vs predictions with and without ice-pack shielding (2.45 MeV PRE channel # 120)

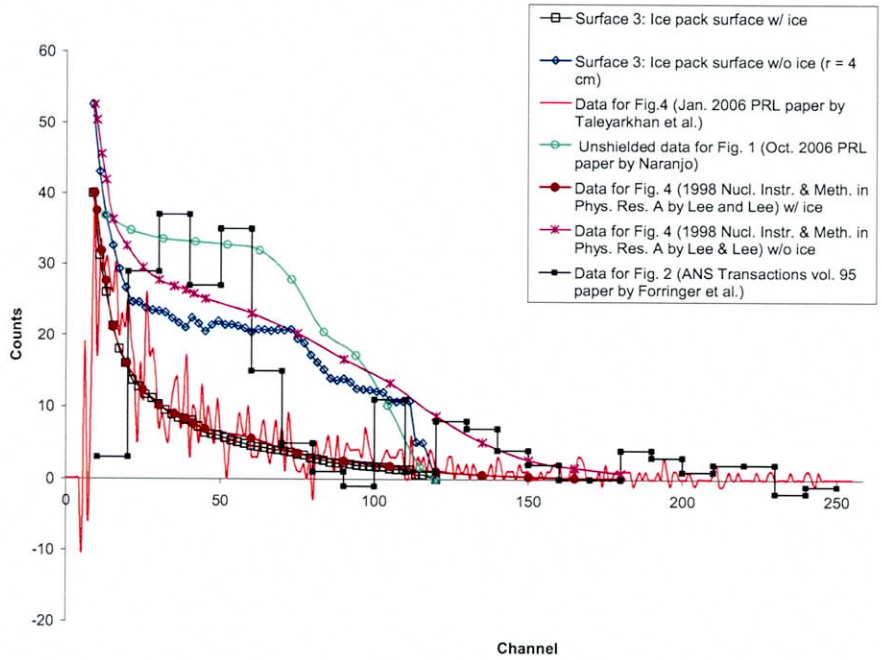

Figure 1E. Measured (published) bubble fusion spectra including Forringer et al. (2006) neutron spectrum data (obtained without ice-pack shielding).

2. Experiments and analyses to address source of measured counts above the 2.45 MeV Proton Recoil Edge (PRE) during bubble fusion experiments

In this section we provide observations and additional experimental data in relation to addressing the question on excess counts obtained during sonofusion experiments above the 2.45 MeV PRE when using a NE-213 type LS detector. Overall, we have noted that about 92-95% of total excess neutron-gated counts are obtained below the 2.45 PRE.

2.1 Discussion and preliminary analyses of the source of excess counts

The source of additional counts above the 2.45 MeV PRE for the LS detector based results shown in our 1/2006 PRL paper (Taleyarkhan et al., 2006) are believed to be due to the following phenomena:

Finite detector resolution

Due to finite detector resolution, the 2.45 MeV PRE turns away from being a sharp rise at the maximum proton recoil energy of 2.45 MeV to a smeared shoulder (Knolls, 1989; Lee, 1998; Dickens, 1983) as already shown in the previous section in Figs. 1C, 1D. We estimate the spread to be in the range of about 50+ light channels above the PRE. Much of the excess counts above the 2.45 MeV PRE occur within ~ 50 channels of the PRE. However, beyond the first ~50 channels over the PRE, the finite resolution feature can not answer why excess counts appear in higher channels and other potential contributors need to be evaluated.

Imperfect PSD-related gamma photon leakage of counts into the neutron window

In our 1/2006 PRL manuscript (Taleyarkhan et al., 2006), we have pointed out that the PSD system settings were ~93% efficient in terms of gating out gamma photons. This also implies that about 7-10% of gamma photons produced during sonofusion will necessarily leak into the neutron window. For the geometry of the setup (Fig. 1 of Taleyarkhan et al., 2006), the test cell was enclosed within ice-pack filled enclosure and in addition, there was significant paraffin-concrete blocks in the vicinity. Neutrons produced from fusion would first downscatter, get to interact with Cl atoms in the test liquid to produce ~ 1.0 to ~1.5 MeV photons, but ultimately, with the abundance of hydrogen atoms around, neutron capture can also result in 2.2 MeV gamma photons. The light pulse height from 2.2 MeV gamma photons encompasses the entire channel range of the multi-channel analyzer (MCA). Therefore, gamma photons could be readily counted above the 2.45 MeV PRE. As an estimate, using the NaI detector we had reported an excess gamma photon count rate of ~ 0.55 γ/s. For a typical experiment lasting about 300 s, would collect ~170 gamma photons, of which about 17 would be able to leak into the neutron window. From a typical excess neutron count population of about 1,000 this amounts to about 1.5% of the total population.

Neutron and gamma counts from fission with uranium in the test cell liquid

The well-established nuclear industry's MCNP nuclear particle transport code [developed and maintained at Los Alamos National Laboratory (LANL)] was utilized to assess the neutron spectrum emitted from the test cell. As noted from Fig. 2A, a significant fraction of the 2.45 MeV neutrons will be down scattered to lower energies before being emitted from the glass surface. About 5-8% of the neutrons were found to be scattered down in the eV range (i.e., total in the energy range of 0 to 1 eV).

Considering the relatively small number density of ^{235}U atoms and also ^{238}U atoms (for which the fast fission threshold is below 2.45 MeV) a preliminary estimate reveals a rather small (< 1%) fraction of the total excess neutron counts above the PRE that may result from fission. This phenomenon is not expected to be a significant contributor.

D-T fusion reactions, ^{13}C-n interactions

The deuterated test liquid includes a small quantity of T (^{3}H) atoms and also a small fraction of the C atoms will be ^{13}C for which possibilities exist to produce nuclear fusion signatures. However, these contributions are assessed as being negligibly small. Only the D-T reaction may produce 14 MeV neutrons and as such, an occasional count in the higher channels.

Neutron pileup

A characteristic feature of acoustic (sono) fusion is that the neutron emission is not random (continuous) but implosion-based, and therefore, time-structured. Until recently, this aspect was not considered as a possibility for excess neutron counts observed above the 2.45 MeV PRE. However, upon reconsideration and based on our recent theory paper (published) in the journal *Phys. of Fluids* (Nigmatulin et al., 2005) new insights have been derived that appear to dictate that neutron pileup effects may play a significant role in sonofusion experiments, and indeed, may present a distinguishing signature in itself. For this purpose, we have conducted a series of experiments and analyses to quantify the relative contribution of neutron pileup (i.e., more than one neutron arriving at the detector within the detector's resolving time) during bubble fusion experimentation.

2.2 Experiments and analyses for neutron pileup effect during sonofusion experiments

The theory of super-compression (Nigmatulin et al., 2005), as applied to our bubble fusion experimentation has revealed that the bubble implosion process leading to D-D fusion for a single bubble in a rapidly imploding cluster will occur within the time span of ~ 0.1 ps and will emit about 12 neutrons per bubble implosion. The bubble cluster consisting of ~1,000 bubbles is estimated to involve about 40 to 50 bubbles within the interior of the cluster where the amplification in implosion intensity produces thermonuclear fusion conditions. There is some uncertainty involved in terms of estimating the time scale over which the 40-50 bubbles implode but conservatively, we estimate that they collectively will implode over 100 ps emitting about 400 to 600 neutrons in total. This gives us an estimate of the instantaneous rate of neutron emission at ~ 5 x 10^{12} n/s. This is a very large rate quantity and must be accounted for in terms of the possibility and consequence of more than one neutron arriving at the LS detector within the resolving time of about ~100 ns (which is considerably longer than the emission period in the ps range).

The assessment of possible neutron pileup effects on our LS detector were conducted both with pulsed neutron source and also via theoretical scoping analyses.

Experiments with pulse-neutron-generator (PNG) for assessing neutron pileup effects

We employed our D-T accelerator driven PNG for assessing whether neutron pileup effects could materialize in our LS detector for neutron pulse rates in the vicinity of expected bubble fusion neutron pulse rates. The PNG system enables stable operation down to 200 Hz during which neutron pulses are emitted over a time span of ~ 5-6 μs (FWHM). The LS detector was placed with it's face about 10cm away from the PNG target. The LS detector response to ^{60}Co and ^{137}Cs sources was obtained. These are shown in Fig. 2B. It is seen that the ^{60}Co 1.2 and 1.3 MeV gamma Compton edge is at channel ~15. From published light curves it would then imply that the 14 MeV PRE would appear around channel 105.

With this calibration, the PSD spectrum was obtained and shown in Fig. 2C. As noted, unlike that for an isotope based neutron source, the D-T fusion based neutron source results in a much larger fraction of neutrons compared to gamma photons. Fusion does not produce gamma photons. Gamma photons are an indirect consequence of fusion neutron interactions with elements of surrounding structures. Based on calibrations with our 1 Ci Pu-Be source it was estimated that the PNG operating with a target voltage of -50 kV and 0.2 kHz would emit ~ 5x10^5 n/s close to the maximum emission level allowed in our laboratory. Since these neutrons are emitted in pulses (~ 10 μs wide at the base and 5 μs FWHM) the instantaneous emission rate is much larger at ~ 5-10 x 10^8 n/s (= 5 x 10^5 / 5-10x10^{-6} / 200). This formed a baseline for estimating instantaneous pulse neutron outputs at other target voltages.

Next, neutron gated pulse-height spectra were obtained at various target voltages ranging from -20 kV to -50 kV. Results of pulse-height spectra are shown in Fig. 2D along with the total neutron counts versus drive voltage in Fig. 2E. As expected, the 14 MeV PRE is seen to occur around channel #105. The rate of neutron counts increase is more rapid at smaller target voltages and decreases as the target voltage increases. This is in line with well-known <σv) D-T reaction cross-sections (Gross, 1984). Figure 2D clearly shows that, while insignificant excess counts are measured over the 14 MeV PRE at target voltages of less than -40 kV, the neutron pileup effect becomes noticeably larger for target voltage of -40kV and above. The variation of the counts above the 14 MeV PRE with target voltage, expressed as a percentage is shown in Fig. 2F. We see from Fig. 2E an exponential increase of neutron pileup induced counts above the PRE, in line with the exponential increase of neutron output rates also seen from Fig. 2E.

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The data shown in Figs. 2D to 2F were obtained with a source-to-detector distance of 10cm compared with 30cm in the published sonofusion experiments. This would imply a factor of ~10 $[= (30/10)^2]$difference based on solid angle effects, and to get about 3% of total counts above the PRE would require a rate of about 10^{11} n/s. This level of output at a distance of about 30cm is comparable to (even though smaller than) the estimated ~10^{12} n/s neutron emission rates for bubble fusion, thereby, forming a reasonable basis to expect that bubble fusion experiments with detection equipment of the type and configurations used will indeed lead to neutron-pileup related effects giving rise to excess counts above the PRE. The amount of excess may amount to ~5-10% of the total neutron counts.

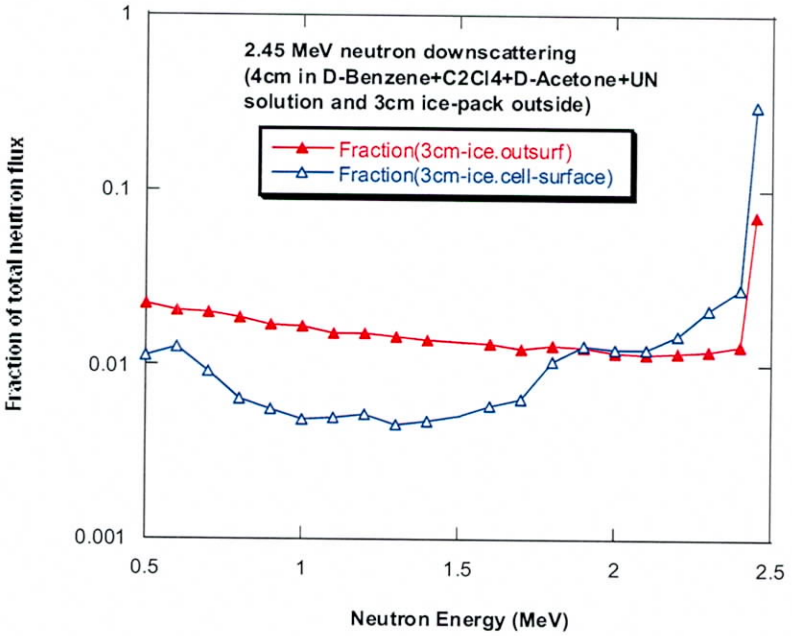

Fig. 2A MCNP5 code calculation for neutron spectrum from test cell

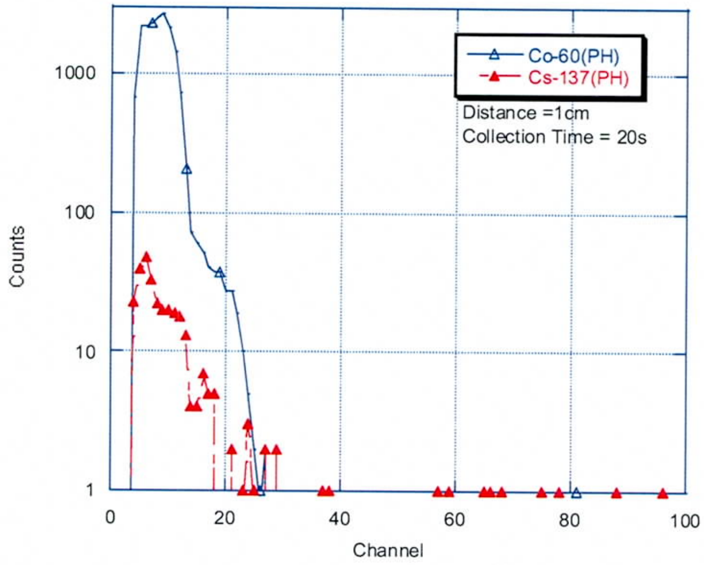

Fig. 2B Calibration spectra with ^{60}Co and ^{137}Cs

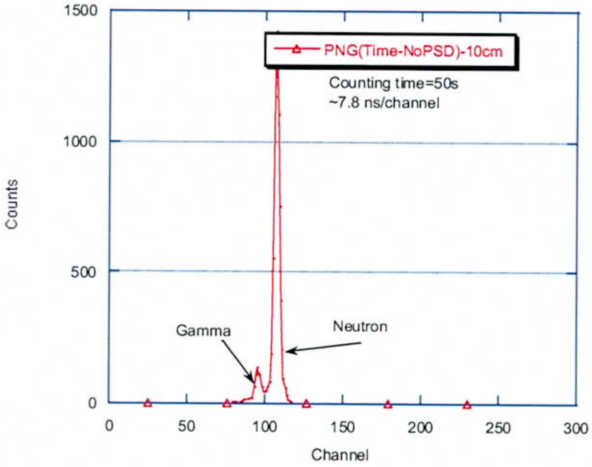

Fig. 2C: Fusion (D-T) source PSD neutron-gamma spectrum with LS detector.

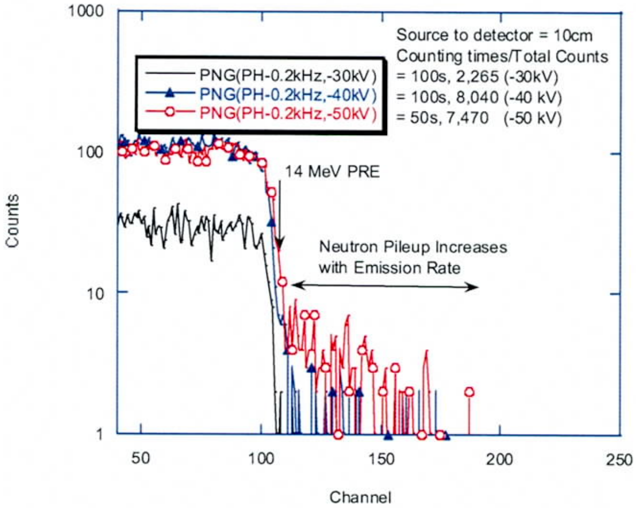

Fig. 2D Pulse height spectra at various PNG target voltages (Note: 50kV data were taken over 50s not 100s)

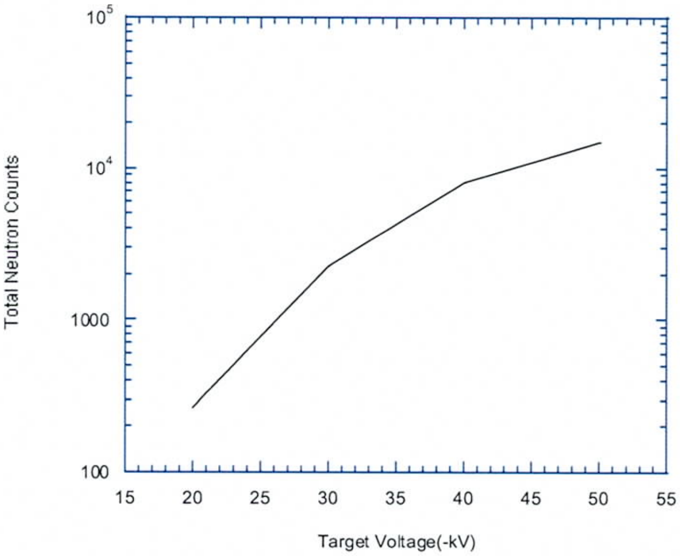

Fig. 2E Neutron counts vs PNG target voltage (data for 50 kV were multiplied by 2 to get equivalent counts over 100s)

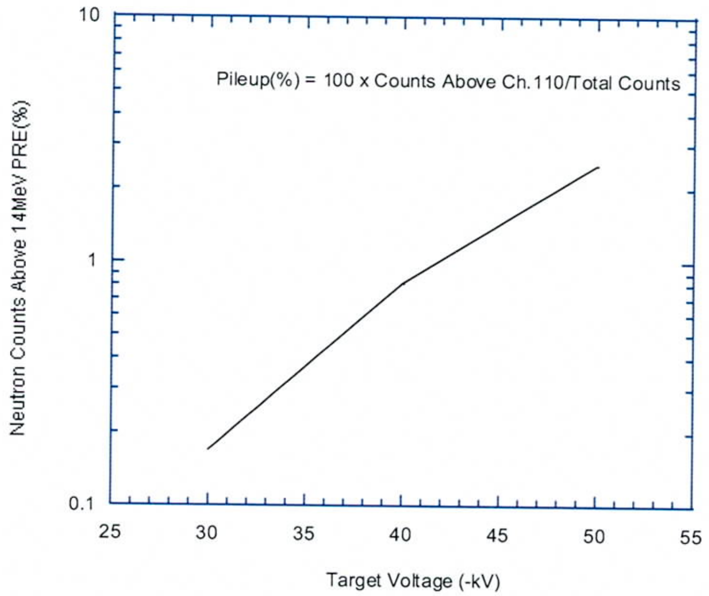

Fig. 2F Neutron pulse pileup (%) versus PNG target voltage

Analytic estimation of magnitude of neutron pileup probability

If N neutrons are emitted during bubble cluster implosion such that they come within the resolving time of the detector, then the probability of a single neutron striking the detector is N x f, where f is the fraction of the solid angle that the detector succumbs.

The probability that two neutrons strike the same detector is $N\ (N-1)f^2$. If the detector efficiency is ε, then the net probability requires that we multiply by ε^2. The LS detector projects an area of about 25 cm^2 so that the solid angle "f" at 30cm from the test cell becomes 0.0022. Since we have estimated that up to 500 neutrons are emitted per bubble cluster implosion, N=500. Based on known scattering cross-sections for C and H atoms, and the composition of NE-213 liquid, for a 5cmx5cm LS detector, the mean free path for a 2.5 MeV neutron is calculated to be ~5.3 cm. We can then assume that ~60% of all neutrons would receive at least 1 collision within the LS liquid, which then would offer a theoretical intrinsic efficiency of at least ~50%. Assuming a typical 50% detector (intrinsic) efficiency gives the net probability of the detector receiving 2 neutrons simultaneously = $500 \times 499 \times (0.0022)^2 \times (0.5)^2 = 0.3$ or about 30%. This estimate necessarily encompasses uncertainties, chiefly related to the value of "N", but on an overall basis, it appears in line with and in the order of magnitude neutron pileup as also witnessed from the experimental observations.

Based on the above, it may be reasonably accepted that neutron pileup will play a first-order role in terms of providing excess counts above the 2.5 MeV PRE and the amount to be expected will be in the experimentally-observed range of ~ 5-10%. By all accounts, it appears reasonable to propose that, such a neutron pileup based excess of counts over the 2.5 MeV PRE should indeed be included as a required signature for validating bubble fusion occurrence. That is, together with the other signatures which we have focused on in earlier publications (Taleyarkhan et al., 2002, 2004, 2006; Xu et al., 2005).

3. 9.19.03 Expts. With Pu-Be source nucleated cavitation experiments with C_6D_6-C_2Cl_4 mixture

Scoping trial experiments were conducted in Rm. G60 of Purdue's Pharmacy Building on 9.19.03 by Drs. J. Cho of Oak Ridge National Laboratory (ORNL) and R. P. Taleyarkhan. During the course of the C-22 review, allegations were raised by J. Walter that time spectra he witnessed a neutron-gamma time spectrum showing a distinct peak of neutron emissions were not archived and as such the data may have been prefabricated. In response, Taleyarkhan has transmitted the date-time stamped archived data for the alleged case.

During discussions on 7.23.07, a C-22 reviewer questioned the quality of the Pu-Be pulse-shape-discrimination (PSD) spectra as being questionable when compared with published PSD spectra where clear separations between gamma and neutron regions are shown. The C-22 reviewer also asked for further support for the difference spectra as constituting a sonofusion signal. This section provides clarification on these questions.

3.1 Causes for PSD distortion in PSD spectra during sonofusion experimentation:

Upon consideration by Taleyarkhan and Professor Robert Block (co-author from Rensselaer Polytechnic Institute (RPI), it is our belief that the PSD spectra for the 9.19.03 experiments encompassed distortions due to electric cross-talk from acoustic (sound) field drive train components. Electric cross-talk based distortions from acoustic drive trains has also recently been reported by UCLA researchers (Camara et al., 2007). It is our belief that for such conditions, the PSD system picks up electric signals from the inductor-amplifier-pzt system and noise on the falling tail of the liquid scintillating (LS) pulse can lead to timing distortions (i.e., the noise can make the time at which the falling tail of the pulse crosses the discriminator jump about).

The calibration source used at UCLA was a 1 mCi Am-Be source (versus the 1,000 mCi Pu-Be source used at Purdue's G60 Pharmacy Lab. On 9.19.03). Unlike in prior ORNL work, the Purdue laboratory's equipment available for use on 9.19.03 included powerful induction coils to aid their amplifier system to drive power to the PZT rings, similar to that used at UCLA. In the ORNL studies, inductor coils were not used. The published UCLA results depicting the very strong influence of electric cross-talk similar to that experienced at Purdue on 9.19.03 are shown in Figs. 3A-B. Under such circumstances, a conservatively-scoped acceptance window is established based on PSD calibration with a known neutron-gamma source. During bubble fusion experiments counts are accepted as valid if they fall within the appropriate gamma and/or neutron acceptance windows.

The degree of distortion of the PSD spectrum for the UCLA studies is similar to that experienced for experiments conducted at Purdue on 9.19.03 as shown in Figures 3C. That is, despite the fact that the time width over which gamma and neutron regions where radiation signals are expected are in the ~10^2 ns range, the effect of electrical cross-talk is

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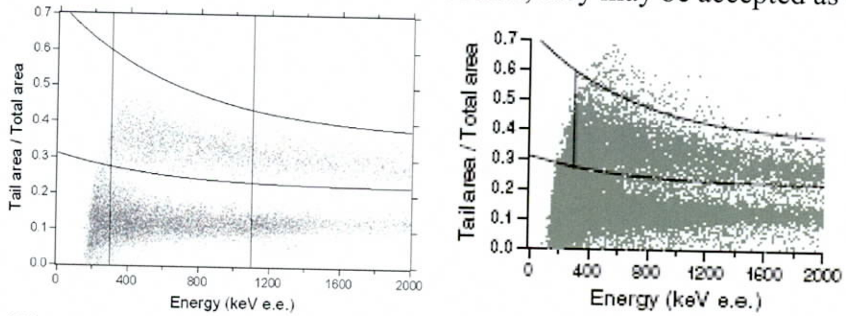
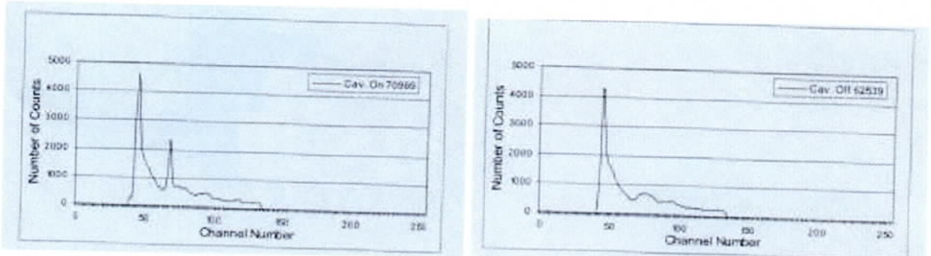
to lead to baseline counts over a much larger time frame in both the neutron as well as the gamma regions. However, if the counts fall within the acceptance window as may be expected from a known calibration source, they may be accepted as valid.



(A) – Acoustic Power Off (UCLA-Ref.1)   (B) – Acoustic Power On (UCLA-Ref.1)

Figure: 3A -Response of the two channels of the neutron detector to 1mCi AmBe source. Upper branch is due to neutrons and lower branch is due to gammas. The experimental acceptance window for 2.5MeV neutrons is indicated on the upper branch; Figure 3B: Same as Figure A, but with acoustic power on. The degree of cross-talk and overlaps between the neutron and gamma regions is evident. Whereas, in Figure A the separation is distinct all the way down to ~ 300 keVee, with acoustic power on, the separation rises to about 700 keVee and above.



C.1 (cavitation on)   C.2 (cavitation off)

Figure 3C. PSD spectra for cavitation on and off conditions for experiments at Purdue's G60 Pharmacy Laboratory on 9.19.2003 (Acoustic Power On at same level for both cases).

3.2 Analysis of cavitation on less cavitation off signals for 9.19.03 experiments

The difference time spectrum for the cases of Figures 3.C are shown below in Figure 3.D. The spectra of Fig. 3C were both obtained at the same acoustic power level for both cavitation on and off conditions. Together with time spectra, pulse height spectra were also taken during the morning of 9.19.03. The difference spectrum shows two fairly distinct peaks, the first peak of counts (width of about 75 ns) directly coincides with the peak in the calibrated gamma time spectrum window. The second peak of counts lasting over about 100 ns is well-separated from the gamma peak and occurs in the anticipated neutron counts acceptance window.

In order to derive evidence for acceptance window regions and characteristics for neutrons and gammas, as part of this evidence package (during July, 2007) we obtained

PSD time spectra taken with a Pu-Be source as well as with a 14 MeV D-T fusion based monoenergetic pulse neutron generator. Results of these two time spectra are shown in Figures 3E and 3F, respectively. The use of a D-T fusion neutron source is relevant for another important reason. It also provides an independent fusion neutron signature figure-of-merit in terms of the relative quantities of neutrons to gamma photons.

By comparing the bubble fusion (9.19.03 experiment) time spectrum (Fig. 3D) with that from the monoenergetic 14 MeV source (Fig. 3E), and that from the Pu-Be isotope source (Fig. 3F) and we notice the following:

- The gamma and neutron peaks of Fig. 3D fall within the acceptance windows and are also consistent for separation in time with that seen from Fig. 3E and Fig. 3F which represent gamma and neutron light pulse decays in the LS detector from a NIST-calibrated isotope source and a D-T fusion neutron-gamma source.
- The gamma-to-neutron counts ratio for the results of the 9.19.03 experiment is consistent with that expected from a nuclear fusion event. That is, the relative counts in the gamma and neutron region are very similar (in the range of ~ 1:4) to that of Fig. 3E (representing neutrons and resulting gammas from a D-T fusion reaction source).
- The gamma-to-neutron counts ratio for the results of the 9.19.03 experiment of about 1:4 is dramatically opposite to that of a Pu-Be and other similar isotope sources where the ratio is close to 1:1 or even in the range of 4:1 for a Cf-252 source.

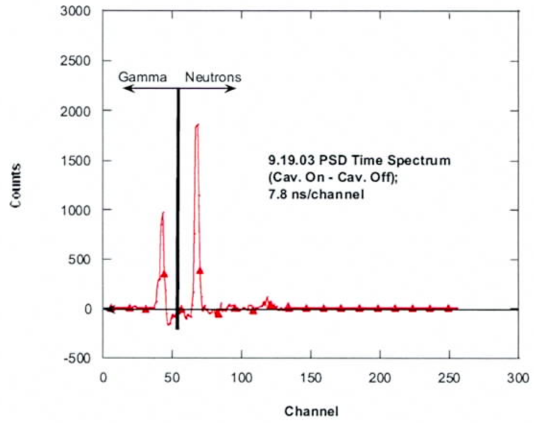


Figure 3.D: Results nuclear emission data (Cavitation On – Cavitation Off) for experiments in G60 Pharmacy Lab. On 9.19.03

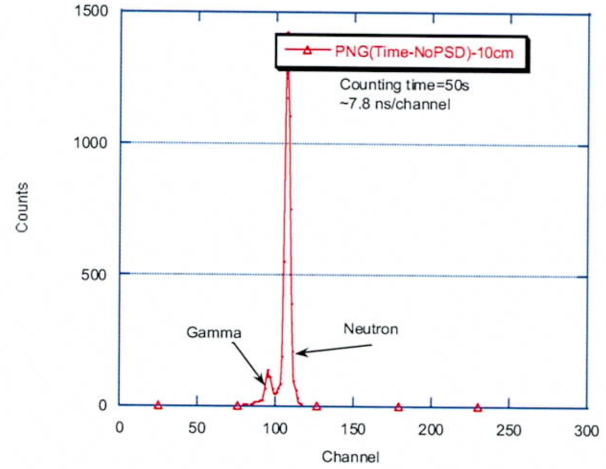


Figure 3E: Fusion (D-T) source PSD neutron-gamma spectrum with LS detector.

Notes: (1) This data taken during 7/2007 (offset present vs 9.19.03 data).
(2) Gamma-to-neutron ratio consistent with Fig. 3C (not Fig. 3F)

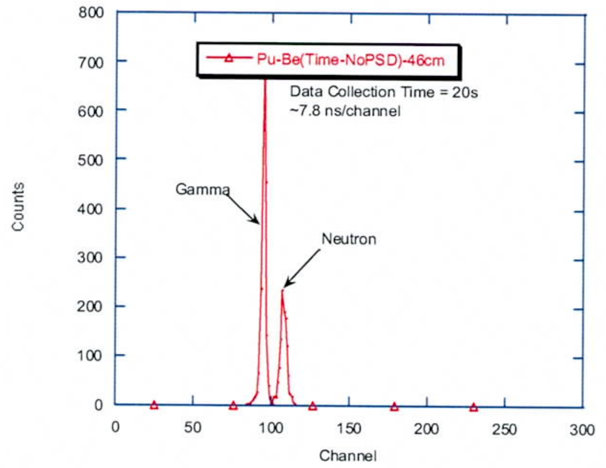


Figure 3.F: Pu-Be isotope source PSD neutron-gamma spectrum with LS detector
(Note: Purdue data taken during 7.2007)

3.3 Analysis of neutron energy via pulse height analysis for 9.19.03 experiments

As part of the scoping experiments, together with time spectra (mentioned by J. Walter in his allegations), pulse-height spectra related data were also obtained on 9.19.03. Fig. 3G shows the pulse-height spectra taken with ^{60}Co and ^{137}Cs mono-energetic gamma sources. From this calibration, the 2.5 MeV neutron PRE is expected to be around channel number 105. Fig. 3H shows the raw pulse-height spectrum taken with cavitation on and cavitation off, respectively. Although small, in comparison to the background neutrons from the 1 Ci Pu-Be source, the cavitation on signal is noticeable. Fig. 3I displays results of the difference spectrum which shows that most of the excess counts are obtained at and below the 2.5 MeV PRE. Consistency with the expected spectrum shape for a 2.5 MeV neutron emitted in a sonofusion setup including shielding and neutron pileup aspects are considered in later sections.

The results of Fig. 3I reveal an excess set of neutron counts of 1,813 over 15 seconds and represents a statistically significant increase of about 12 standard deviations.

The Fig. 3D data were obtained over a relatively longer time span of 50 seconds during which a total of 8,430 excess neutron-cum-gamma counts were obtained. Neutron counts from Fig. 3D amount to about 6,459. This is consistent in overall magnitude with the pulse-height analsysis based time-corrected excess neutron counts from Fig. 3I of ~ 6,000 [= 1,813 x (50/15)].

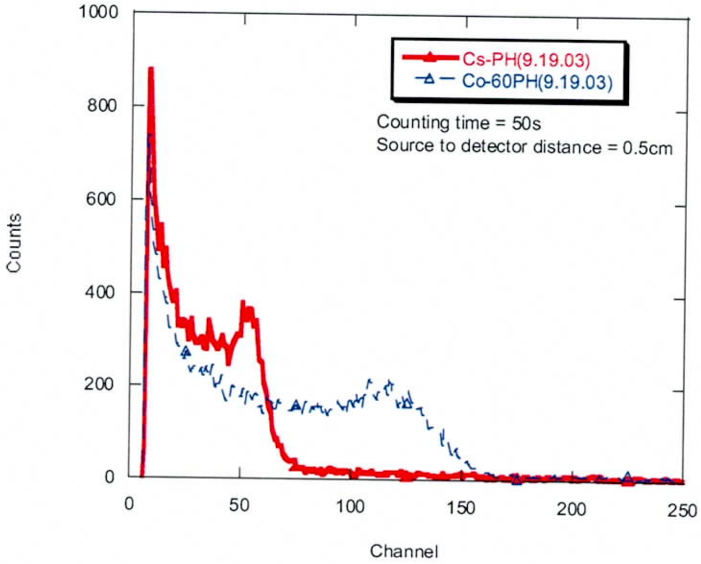


Figure 3G: Pulse height spectra for ^{60}Co and ^{137}Cs

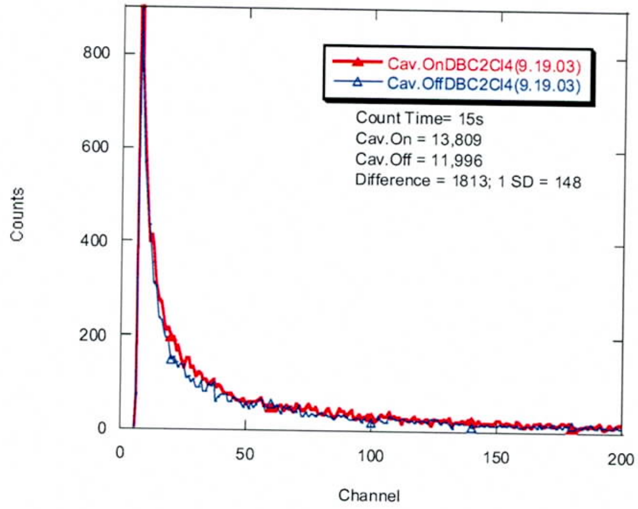


Figure 3H: Cavitation on and off pulse-height spectra

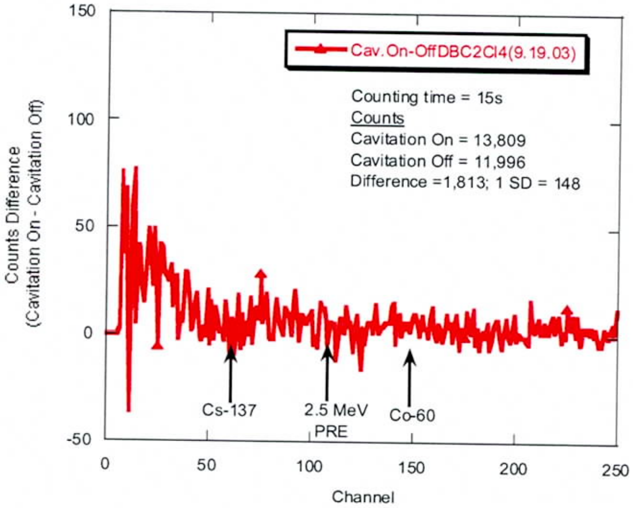


Figure 3I: Excess counts pulse-height spectrum for 9.19.03 test.

Overall conclusions for Section 3

It is categorically stated that the PSD spectrum behavior displayed in Fig. 3C has NEVER been noted in any of our control experiments with non-deuterated test liquids that we have experimented with over the past 10 years.

Based on the direct PSD calibrations with a D-T fusion neutron source, it has been shown that the excess emissions of Fig. 3C fall within the acceptance windows and are consistent with what one may expect from a bubble fusion event. The pulse-height spectrum also taken on that same day also offers statistically significant emission spectrum in which most of the excess pulse-heights are at and below the 2.45 MeV PRE.

In good faith, we believe a reasonably sound explanation has been provided for the PSD spectrum distortion (which has also been reported by others in the literature) and for determining valid acceptance windows for valid counts. However, the excess emissions are statistically significant and appear consistent with the PSD acceptance windows for fusion neutrons of 2.45 MeV energy.

It is accepted that the limited data taken for the scoping experiment on the morning of 9.19.03 are not considered sufficient for publication, especially since control experiments with non-deuterated C_6H_6-C_2Cl_4 mixture were not conducted due to time constraints during the visit by ORNL staff.

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