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A Novel Method for Modeling the Neutron Time of Flight (nTOF) Detector Response in Current Mode to Inertial Confinement Fusion Experiments

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A Novel Method for Modeling the Neutron Time of Flight (nTOF) Detector Response in Current Mode to Inertial Confinement Fusion Experiments

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ABSTRACT

There are several machines in this country that produce short bursts of neutrons for various applications. A few examples are the Z-machine, operated by Sandia National Laboratories in Albuquerque, NM[†]; the OMEGA Laser Facility at the University of Rochester in Rochester, NY[§]; and the National Ignition Facility (NIF) operated by the Department of Energy at Lawrence Livermore National Laboratory in Livermore, California[‡]. They all incorporate neutron time of flight (nTOF) detectors which measure neutron yield, and the shapes of the waveforms from these detectors contain germane

[†]Matzen, K., *Phys. Plasmas* **4**, 1519 (1997).

[§]T.R. Boehly, D.L. Brown, R.S. Craxton, R.L. Keck, J.P. Knauer, J.H. Kelly, T.J. Kessler, S.A. Kumpan, S.J. Loucks, S.A. Letzring, F.J. Marshall, R.L. McCrory, S.F.B. Mose, W. Seka, J.M. Soures, and C.P. Verdon, "Initial performance results of the OMEGA laser system," *Opt. Commun.*, vol. 133, pp. 495-506, 1997.

[‡]E.I. Moses, "The National Ignition Facility: Status and plans for the experimental program," *Fusion Sci. Technol.*, vol 44, pp. 11-18, 2003.

information about the plasma conditions that produce the neutrons. However, the signals can also be “clouded” by a certain fraction of neutrons that scatter off structural components and also arrive at the detectors, thereby making analysis of the plasma conditions more difficult. These detectors operate in current mode – i.e., they have no discrimination, and all the photomultiplier anode charges are integrated rather than counted individually as they are in single event counting. Up to now, there has not been a method for modeling an nTOF detector operating in current mode. MCNP-PoliMi[▽] was developed in 2002 to simulate neutron and gamma-ray detection in a plastic scintillator, which produces a collision data output table about each neutron and photon interaction occurring within the scintillator; however, the post-processing code which accompanies MCNP-PoliMi assumes a detector operating in *single-event counting mode* and not current mode. Therefore, the idea for this work had been born: could a new post-processing code be written to simulate an nTOF detector operating in current mode? And if so, could this process be used to address such issues as the impact of neutron scattering on the primary signal? Also, could it possibly even identify sources of scattering (i.e., structural materials) that could be removed or modified to produce “cleaner” neutron signals?

This process was first developed and then applied to the axial neutron time of flight detectors at the Z-Facility mentioned above. First, MCNP-PoliMi was used to model relevant portions of the facility between the source and the detector locations.

[▽]S.A. Pozzi, E. Padovani, M. Marseguerra, Nucl. Instr. and Meth. A 513 (2003) 550-558.

To obtain useful statistics, variance reduction was utilized. Then, the resulting collision output table produced by MCNP-PoliMi was further analyzed by a MATLAB post-processing code. This converted the energy deposited by neutron and photon interactions in the plastic scintillator (i.e., nTOF detector) into light output, in units of MeVee^φ (electron equivalent) vs time. The time response of the detector was then folded into the signal via another MATLAB code. The simulated response was then compared with experimental data and shown to be in good agreement.

To address the issue of neutron scattering, an “Ideal Case,” (i.e., a plastic scintillator was placed at the same distance from the source for each detector location) with no structural components in the problem. This was done to produce as “pure” a neutron signal as possible. The simulated waveform from this “Ideal Case” was then compared with the simulated data from the “Full Scale” geometry (i.e., the detector at the same location, but with all the structural materials now included). The “Ideal Case” was subtracted from the “Full Scale” geometry case, and this was determined to be the contribution due to scattering. The time response was deconvolved out of the empirical data, and the contribution due to scattering was then subtracted out of it. A transformation was then made from dN/dt to dN/dE to obtain neutron spectra at two different detector locations.

^φ1 MeVee = amount of light produced by 1 MeV deposited by a Compton scattered electron.

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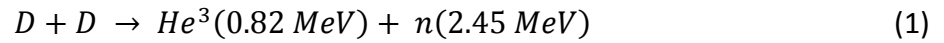
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CHAPTER 1

INTRODUCTION

Neutron Time of Flight (nTOF) detectors are fielded on neutron producing experiments on Sandia National Laboratories' Z machine [1,2]. Some of these are Inertial Confinement Fusion [3] (ICF) experiments using deuterium filled capsules. In addition, these detectors are used to measure the neutron yield and neutron energy from the reaction:



The detectors consist of 2.54 cm (1 inch) thick by 7.62 cm (3 inch) diameter Bicron 418 plastic scintillator coupled via UVT plastic light guides to fast Hamamatsu R5945 mesh-type photomultiplier tubes. Two of these ("side-on") detectors were located along a single line-of-sight at 102° with respect to the z-pinch axis at distances of 742 cm (24.34 ft) and 839 cm (27.53 ft). Another pair of "on-axis" detectors were located on a single line of sight along the z-axis at distances of 730 cm (23.95 ft) and 809 cm (26.54 ft), below the target chamber center (TCC). A schematic of all the nTOF detector positions relative to the ICF capsule is shown in Figure 1.

The physical dimensions of the Z-Facility are quite large, with meters of distance between the source and the detectors. An axial cross-sectional diagram of the facility is shown below in Figure 2, which includes the "on-axis" nTOF detectors located in the basement "pig," which actually had to be fielded 3 ° off axis, to allow space for other

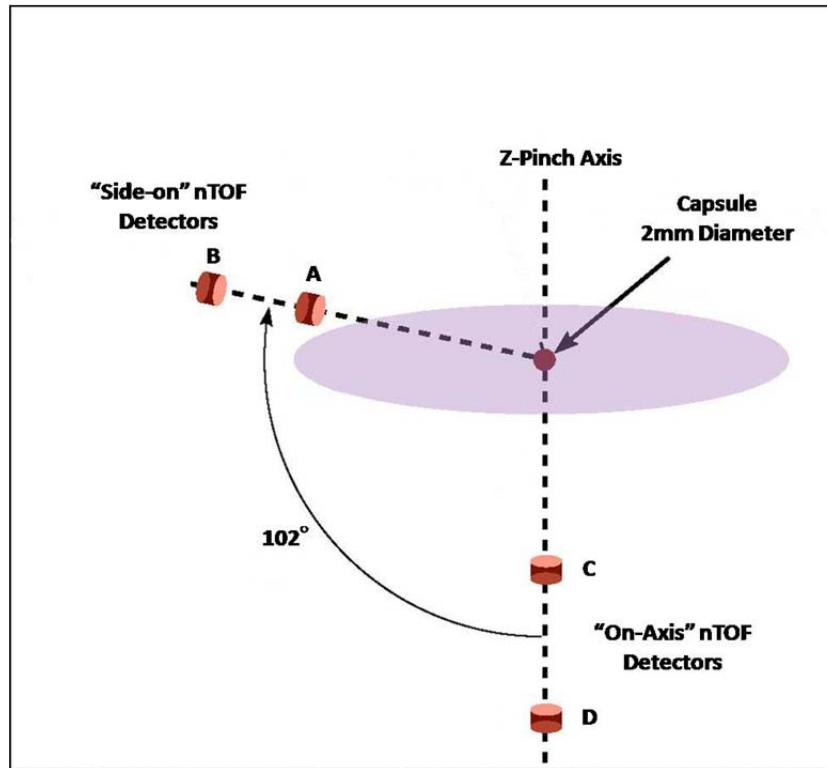


Figure 1. Schematic of nTOF Detector Positions relative to ICF Capsule.

diagnostics sharing the axial view. Due to the intense bremsstrahlung background characteristically produced by Z pinches [4], 20.32 cm (8 inches) of lead shielding was required to prevent the detectors from producing a non-linear response due to saturation of the PMT in the extreme x-ray pulse and not recovering before the neutron signal arrived.

To acquire realistic nTOF signals at the detector, part of the Z-Facility, particularly between the source (Z-pinch) and detector locations would have to be modeled with MCNP [5], with a reasonable degree of detail. To include the axial nTOF detectors in the basement below TCC, the model would extend from the pinch location downward, comprising three of the magnetically insulated transmission lines (MITLs), the stack (which makes up the vacuum chamber), the bottom lid, and the radiation

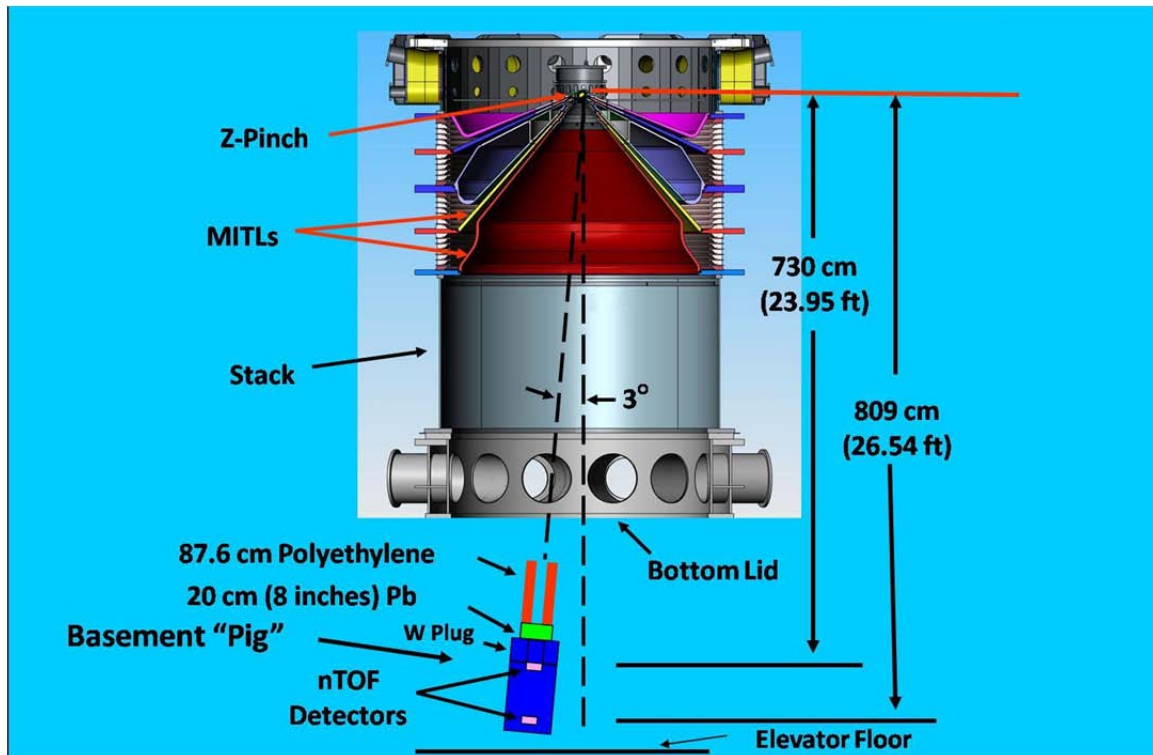


Figure 2. Axial Cross Sectional Diagram of the Z-Facility from the Z-pinch to the Basement “Pig,” three degrees off-axis, and ~7m – 8m (23 ft – 26 ft) away from the pinch (TCC).

shield in the basement (i.e., the “pig”) housing the two nTOF detectors. In addition to the pig, a polyethylene collimator 87.6 cm (34.49 in) long with an inner diameter of 7.62 cm (3in) that was fixed to the top of the pig was also included. A cross section view near TCC of the model used is shown in Figure 3; the entire model comprises over 2400 cells, and more than 900 surfaces. The great number of cells and surfaces were required due to the large scope of the machine. Although the basic *geometry* of the machine is straightforward – the vacuum chamber is a large cylinder, the MITLs (magnetically insulated transmission lines, shown in Figure 2) are large cones; even the “pig” in the basement has a cylindrical geometry, and these basic shapes all exist within MCNP, however, one cannot assign, for example, one cylindrical cell to be the vacuum

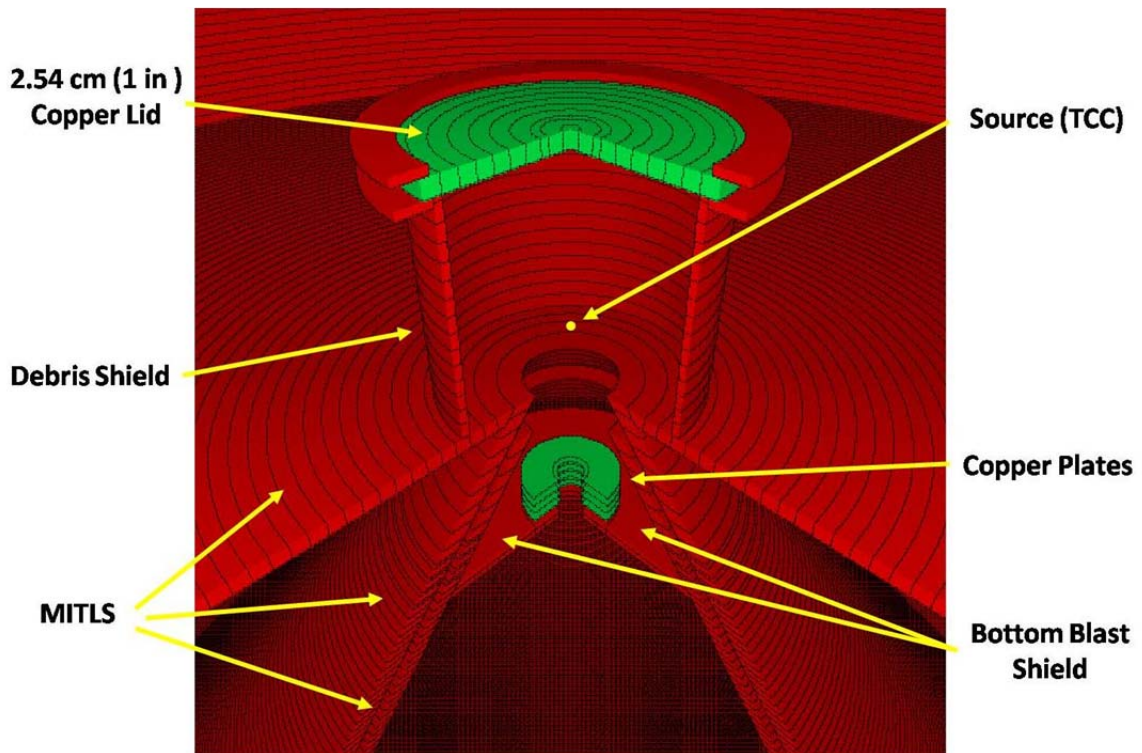


Figure 3. 3-D View near Source (TCC). The MCNP-PoliMi model comprised of over more than 2400 cells and 900 surfaces. The overall geometry is cylindrical, and the lines seen in the figure are individual surfaces making up each slice, or cell.

chamber, with an inner diameter of 3.20 m (10 ft, 6 inches) and a length from TCC downward of 5.3 m (17 feet, 5 inches). To track particles effectively, MCNP requires that the optical thickness of cell dimensions be on the order of *one mean free path* [5]. For DD neutrons of 2.45 MeV through stainless steel, the mean free path is 3.33 cm (1.31 inches). Therefore, a great number of cells and surfaces were needed to divide the vacuum chamber into thin *slices* (cells) – the same with the MITLS, and the same with the basement “pig” – in fact, the same with the entire geometry of the problem. Making simple slices of the geometry also allowed MCNP to run faster, since it prefers the problem geometry made up of many simple cells rather than fewer more com-

plicated cells [5]. The slices can be seen in the three-dimensional view near the source, in Figure 3. The overall geometry was cylindrical, and the lines seen in Figure 3 are individual surfaces making up each slice, or cell.

The “pig” which housed the two nTOF detectors was originally designed to field an x-ray camera, and was not designed as a neutron shield; however, it was the only shield available at the time, and had ample space to accommodate the two nTOF detectors. Also, being comprised of high Z materials – namely lead and tungsten – made it an effective shield against the intense bremsstrahlung background. The original basement pig compared to its MCNP model are shown in Figure 4. As seen in the

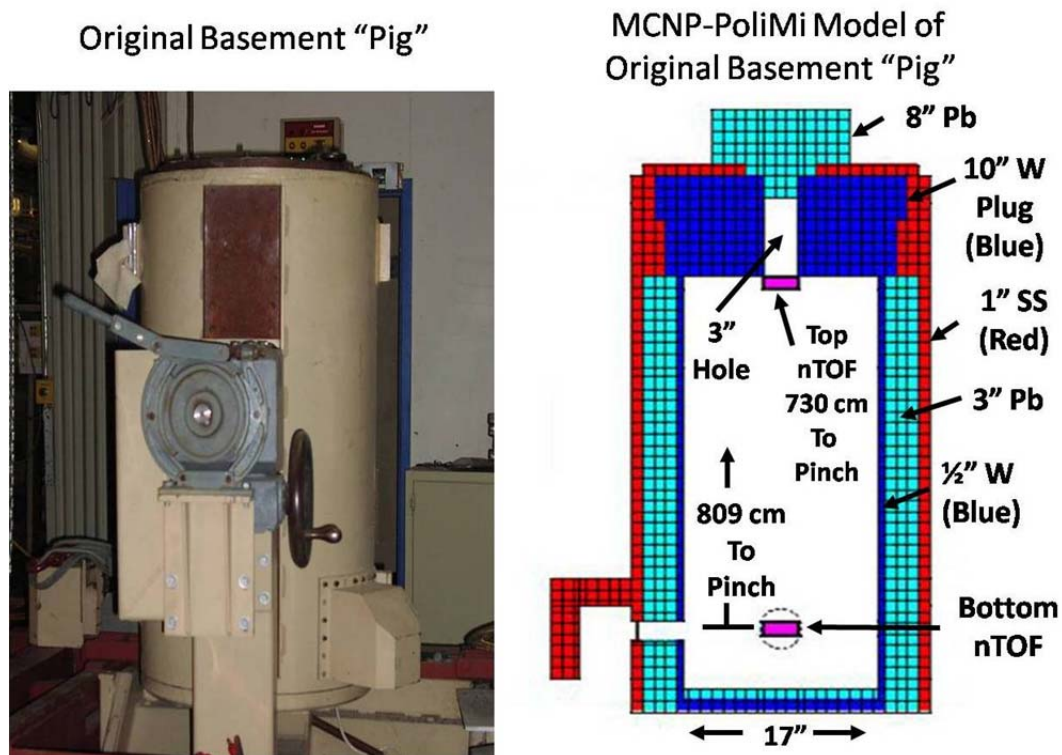


Figure 4. Original Basement “Pig” and its MCNP-PoliMi model. It was not designed as a neutron shield; it originally housed an x-ray camera. The lead plug located on top (right) was necessary to attenuate the intense x-ray pulse at shot time so the detectors would not saturate.

figure, an additional 20.32 cm (8 in) of lead were added to the top of the pig to cover the 7.62 cm (3 in) aperture. This shielding was necessary to reduce the bremsstrahlung pulse in the detectors. Without it, that intense x-ray pulse would saturate the two nTOFs, and they would not recover in time to see the DD neutron pulse arriving over 300 ns later.

As mentioned above, a polyethylene collimator 87.6 cm (34.49 in) long with a 7.62 cm (3 in) inner aperture was located on top of the pig. A cross section of the polyethylene collimator and top of the pig is shown in Figure 5. Below the 20.32 cm (8

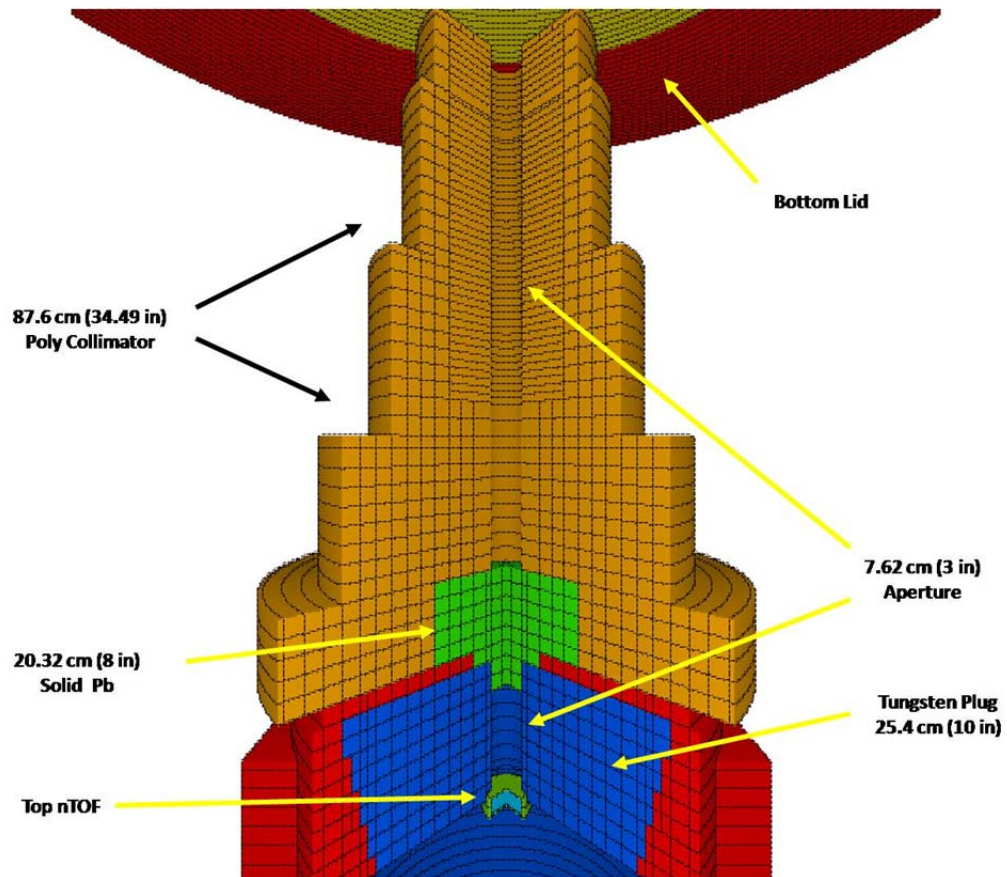


Figure 5. 3-D View of Polyethylene Collimator and Top nTOF. The detector is located at the base of the 7.62 cm (3 in) aperture.

in) of lead is a tungsten plug 25.4 cm (10 in) long with a 7.62 cm (3 in) aperture. The top nTOF detector is located at the base of the aperture. A cross section of the lower part of the pig showing both the top and bottom nTOF detectors, part of the pig chassis and elevator floor is shown in Figure 6.

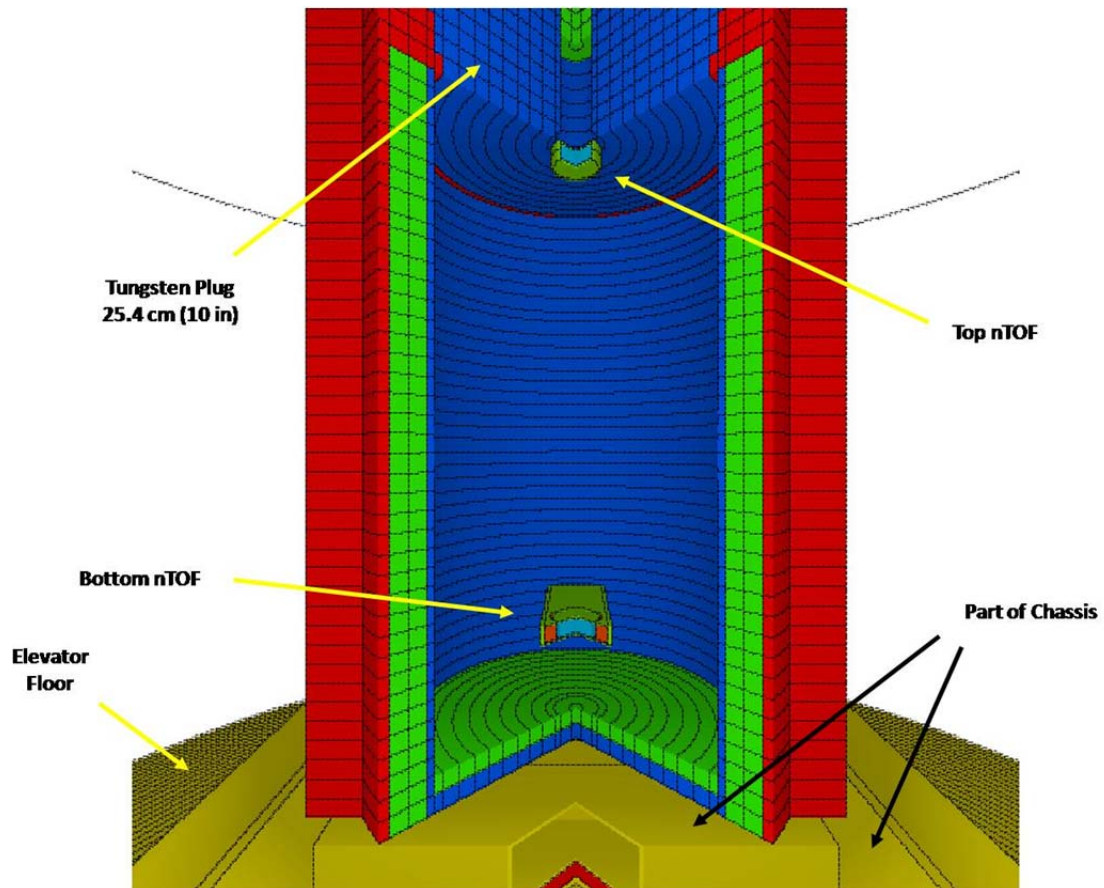


Figure 6. 3-D View of Top and Bottom nTOF Detectors. Part of the chassis, the elevator floor and tungsten plug can also be seen.

CHAPTER 2

MCNP-PoliMi

MCNP-PoliMi [6] is a user-modified version of a general purpose, continuous-energy, time-dependent, Monte Carlo N-Particle code, version 4C [5] that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. In it, the user creates an input file which contains: the geometry of the problem, description of materials in the problem, the location and characteristics of the source, and the type of answers or tallies desired. It has been used to simulate measurements made by the Nuclear Materials Identification System (NMIS) [7], and has been validated [8]. It was developed at the Polytechnic of Milan, Italy (which gives rise to its name; PoliMi stands for “**P**olitecnico di **M**ilano”) by E. Padovani and S.A. Pozzi, in 2002 [9]. It is a versatile tool to simulate particle interactions and detection processes, and consists of two stages: first, an input file is run which produces a collision data output table, then the PoliMi MATLAB post-processing code [9] analyzes the table and produces a detector response. In this case, the MATLAB post-processing code was rewritten for this work to simulate a detector response produced by an nTOF detector operated in current mode [10].

Detailed information about each neutron and photon interaction occurring in user-specified cells is reported in the collision data output table. Interaction type, target nucleus, energy deposited in the collision, time at which the collision occurred, and number of scatterings are among the pertinent data. A partial sample of the collision data output table is shown below in Table I. The modified MATLAB post-processing

code reads the collision data output table, and converts the energy deposited in MeV to MeVee (electron equivalent) [11] according to the incident particle's *response function*.

Table I.

Excerpt from MCNP-PoliMi Collision Data Output Table.

<u>Projectile Type[§]</u>	<u>Interaction Type[▽]</u>	<u>Target Nucleus[†]</u>	<u>Energy Deposited in Collision (MeV)</u>	<u>Time (Shakes)^Φ</u>	<u>Number Of Scatterings</u>
1	-99	1001	0.52526	43.55	1
1	-99	1001	0.18983	84.74	2
1	-99	1001	0.01374	84.76	1
1	-99	6000	0.01628	75.01	3
1	-99	6000	0.00892	75.13	3
1	-99	1001	0.02221	75.27	3
1	-99	1001	0.01146	75.31	4
1	-99	6000	0.00028	75.43	2
1	-99	1001	0.00036	75.49	1
1	-99	1001	0.00080	78.30	3
1	-99	6000	0.00012	78.74	2
1	-99	6000	0.01170	74.81	1
2	1	6	1.94631	62.74	1

[§]1 = Neutron; 2 = photon; [▽]-99 = elastic scattering; 1 = Compton scattering; -1 = inelastic scattering; [†]1001 and 1 = Hydrogen; 6000 and 6 = Carbon; ^Φ1 Shake = 10 ns = 10⁻⁸ sec.

CHAPTER 3

RESPONSE FUNCTIONS

The simulation of the detector pulse requires that the energy deposited in the detector by neutrons and photons be converted into light output by using measured detector response functions [9]. Neutrons are detected primarily by elastic scattering on hydrogen, with the measured response function fit to the following quadratic equation for a plastic scintillator as shown in equation (2):

$$L = 0.0364 * E_n^2 + 0.125 * E_n \quad (2)$$

where E_n is the energy deposited by the neutron on hydrogen (MeV) and L is the measured light output (MeVee). The resulting recoil protons quickly transfer their kinetic energy to luminescent states in the scintillator [12]. Neutron interactions with carbon are assumed to generate a very small light output equal to:

$$L = 0.02 * E_n \quad (3)$$

where E_n is the energy deposited by the neutron on carbon (MeV) and L is the corresponding light output (MeVee). (This is an approximation by the authors of PoliMi, due to the fact that the light conversion of the recoil carbons is roughly one order of magnitude lower than that of the recoil protons; in the post-processing program they arbitrarily imposed that the kinetic energy of carbon nuclei be converted to light with a constant efficiency factor of 0.02 MeVee per MeV [13]). In these reactions, energy is lost by the neutron without significant light production.

Photons, on the other hand, are detected primarily by Compton scattering, and the pulse-height to energy deposited response is very close to linear:

$$L = E_\gamma \quad (4)$$

where E_γ is the energy deposited by the photon (MeV) and L is the measured light output (MeVee). A plot of the response function for a neutron on hydrogen according to the response functions of PoliMi (equation 2 above) and Stanton [14] as well as Czirr [15] and Verbinski [16] are shown in Figure 7. This displays not only the comparison of PoliMi's, Stanton's, Czirr's and Verbinski's response functions, but also the nonlinear nature of scintillator light output for non-photons.

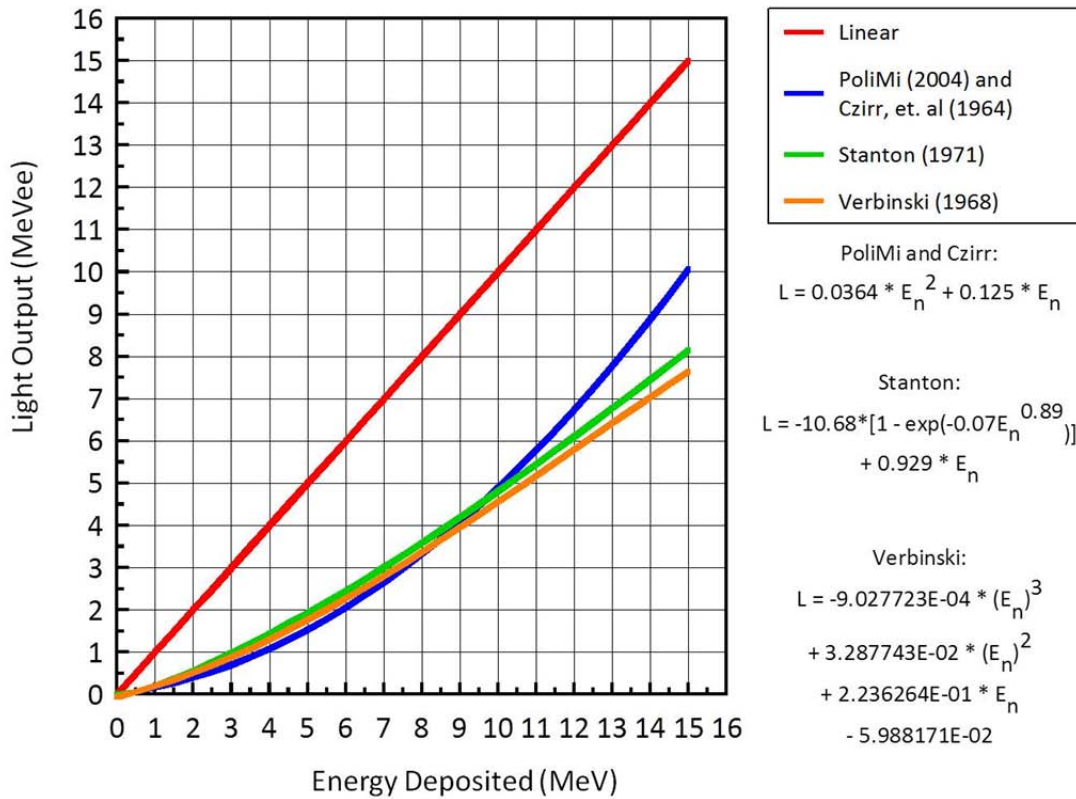


Figure 7. The nonlinearity of Scintillator Light Output. Comparison of the response functions of PoliMi, Czirr, Stanton and Verbinski for a neutron on hydrogen. PoliMi and Czirr compare well with each other, and Stanton and Verbinski are similar. They all produce light output which is decidedly nonlinear in nature.

ENERGY DEPOSITED VS LIGHT OUTPUT

There has been a trend in the community when doing calculations of this nature to only look at the energy deposited in the scintillator as opposed to the light output produced from neutron interactions with hydrogen and carbon (in MeVee). Certainly, MCNP accommodates energy deposition tallies, such as an F6 (MeV/gram) [5], but in reality, this is not the true “output” from the scintillator. Without the correct response functions listed above, which have been measured by Stanton [14], Czirr [15], Verbinski [16] and Polimi [17] which convert energy deposited (MeV) to light output (MeVee), one will *grossly overestimate* the amount of light output which is produced. An illustrative example is shown in Figure 8. For the same MCNPX [18] calculation, the F6 Tally (MeV/gram) was compared to the light output produced by the process discussed in this work. At the left in Figure 8 is the F6 Tally (red) compared to the calculated light output (blue). As can be seen, the F6 Tally crudely resembles the calculated light output, but once they are area normalized (on the right) there is no longer any resemblance, showing that the F6 Tally is overestimating the amount of light output produced greater than an order of magnitude. When the calculated light output in Figure 8 (blue, left) is compared with the actual data and area normalized (as shown, for example, in Figure 15 on page 30) one can see that the calculation is very close to the data, both in terms of shape and magnitude.

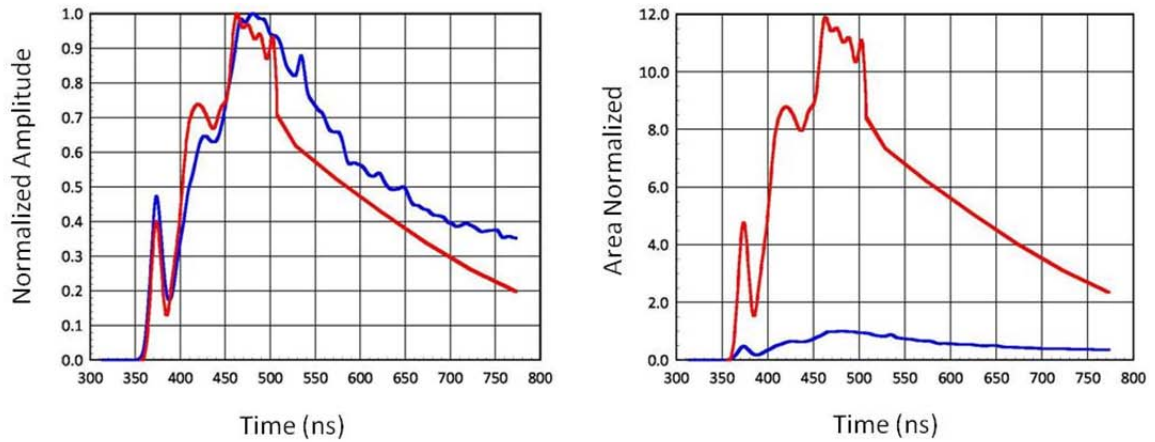


Figure 8. Energy Deposition (MeV) vs Light Output (MeVee). For the same number of histories, light output was produced using the response functions above, and shown in blue; this is compared to an F6 energy deposition tally in MCNPX (MeV/gram, red). On the left one can see that the red crudely resembles the blue *in shape*, but once they are area normalized (on the right) there is no longer any resemblance, showing that the F6 Tally is overestimating the amount of light produced greater than an order of magnitude. When the calculated light output (blue, left) is compared to the actual data and area normalized (Figure 15, p. 30) the calculation compares well to the data, both in terms of shape and magnitude.

CHAPTER 4

THE POST-PROCESSING CODE

The post-processing code was written in MATLAB, which loads the collision data output table, then sorts it in terms of increasing time (column 6 in Table I, p. 9), then converts the energy deposited in MeV into light output (MeVee) according to the incident particle (either a neutron or photon) and the target nucleus (H or C), then sums all the light outputs into time bins which correspond to the resolution of the data digitizer recording (in this case, 200 ps time bins used on Tektronix TVS645 digitizers [19]), then plots the light output versus time. An additional code written for this work convolves the actual time response of the detector with the MATLAB output where it can be compared with empirical data. A flowchart of the post-processing code with these additional steps is shown in Figure 9.

Figure 10 shows an early plot of light output versus time only (with no convolved detector response) for an analog Monte Carlo run. The term “analog” means assigning weight equal to unity to all of the particles generated at the source and to each of the secondary particles born at a collision. The analog model is the simplest Monte Carlo model for particle transport problems because it uses natural probabilities that various events occur (e.g., collision, capture, scattering, etc.). Particles are followed from event to event, and the next event is always sampled (using the random number generator) from a number of possible next events according to the natural event probabilities.

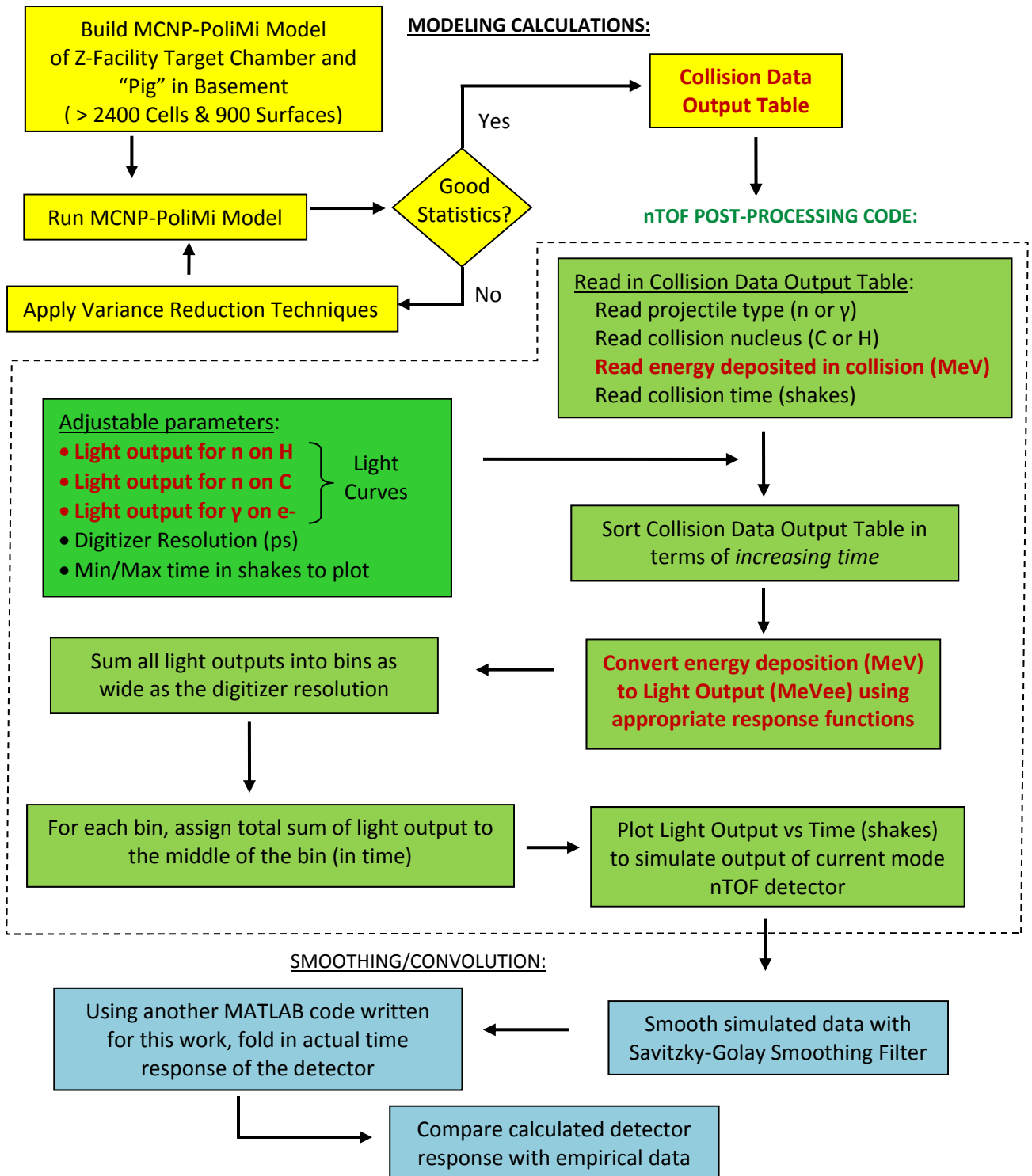


Figure 9. Flowchart of the post-processing code. It reads the collision output table produced in an MCNP-PoliMi model, sorts is in terms of increasing time, converts energy deposited (MeV) into light output (MeVee) with appropriate response functions, sums the light output into time bins equal to the digitizer's resolution, and plots the result. The raw data is then smoothed with a Savitzky-Golay smoothing filter. An additional code then convolves the smoothed data with the actual time response of the detector, where it can then be compared with empirical data.

This way, analog Monte Carlo is directly analogous to naturally occurring transport. It works well when a significant fraction of the particles contribute to the tally estimate; however, in most real-world type problems with complicated geometries and large source-to-detector distances, the fraction of particles detected can be very small (less than 10^{-06}). For these cases analog Monte Carlo fails because few, if any, of the particles get tallied, and the statistical uncertainty in the answer is unacceptable. The MCNP results in Figure 10 is a case in point; on a desktop PC, it ran the maximum amount of particles (2.0E09), and it took 43 hours. Due to the distance from the source (~8m) and amount of material between the detectors and source (20.32 cm Pb, the bottom lid, etc.), the probability of transporting a particle from the Z-pinch (TCC) to an nTOF detector in the basement becomes *vanishingly small* when using analog Monte Carlo. Therefore, *non-analog* Monte Carlo techniques had to be implemented. Non-analog Monte Carlo models estimate the same average value as the analog Monte Carlo model, but often make the variance (uncertainty) of the estimate much smaller than the variance for the analog estimate. In practical terms, this means that problems that would be impossible to solve in *days* of computer time can now be solved in *minutes* of computer time.

There are many non-analog techniques, and they all are meant to increase the odds that a particle contributes to a tally. To ensure that the average score is the same in the nonanalog model as in the analog model, the score is modified to remove the effect of biasing (changing) the natural odds. Thus, if a particle is artificially made q times as likely to execute a given random walk (i.e., travel in a particular direction

toward a detector), then the particle's score is weighted by (multiplied by) $1/q$. The average score is thus preserved, because it is the sum over all random walks. In this way, nonanalog – or variance reduction – techniques (VRTs) can often decrease the

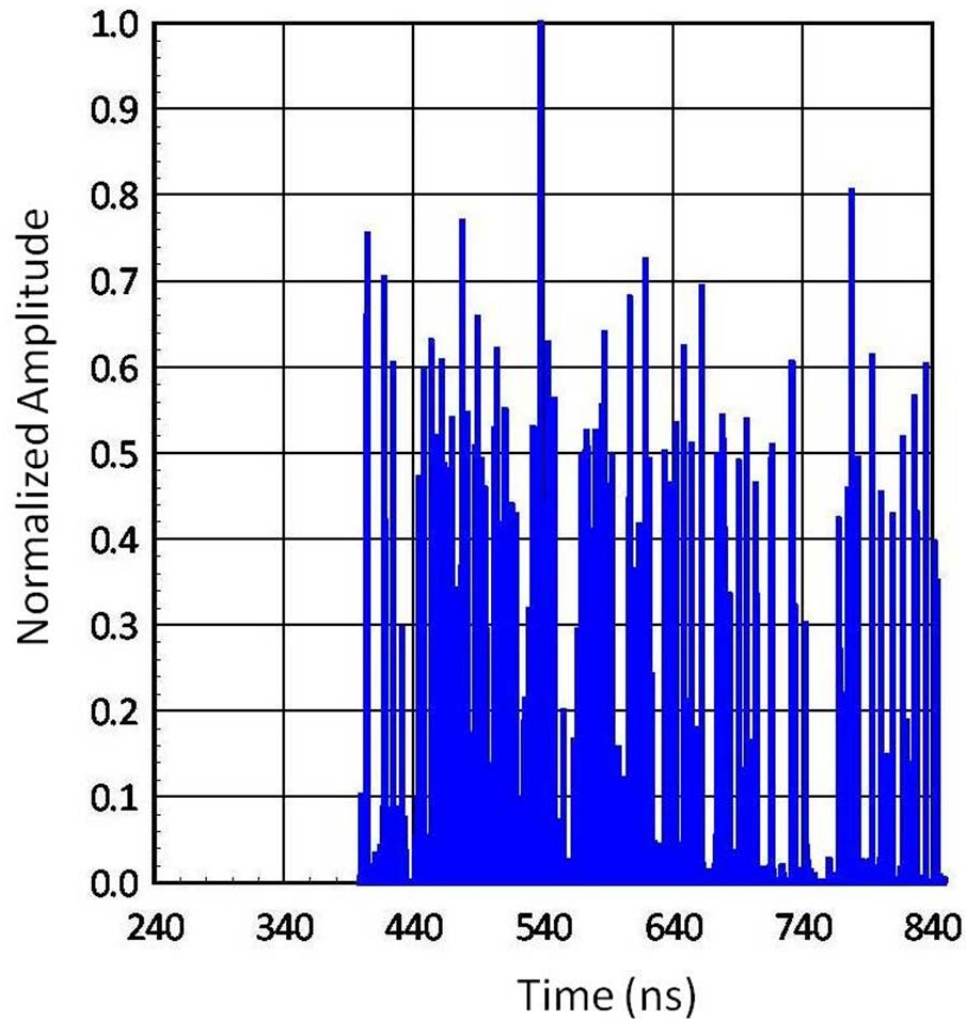


Figure 10. An analog MCNP-PoliMi model (i.e., without any Variance Reduction Techniques applied). This was run with the maximum amount of particles (2.0E09), and it took 43 hours of computer time.

relative error by sampling naturally *rare* events with an *unnaturally high frequency* and weighting the tallies appropriately.

CHAPTER 5

VARIANCE REDUCTION

Central to the art of variance reduction is the concept of particle weight [20]. To simulate the transport of a large number of particles, it is not necessary to follow all of them. Rather, it is only necessary to follow a statistically significant sample of particle “histories.” Each history is assigned a weight that, in some sense, represents the number of particles modeled. At any time during the random walk of the particle, it may be split into N particle “tracks” provided that the weight is divided by N . Alternatively, it may be killed with probability $1/N$ (“Russian Roulette”) at any time provided the weight of surviving particles is multiplied by N . All variance reduction schemes work by putting a large number of particles of low weight in regions of interest and allowing only a small number of particles with high weight in unimportant regions of the problem. A summary of all the VRTs that proved useful for this work are shown below.

WEIGHT WINDOWS

The weight windows method is a *population control method* which artificially increases/decreases the number of particles in spatial or energy regions that are important/unimportant to the tally score. It is another form of geometry splitting and Russian Roulette, where a particle crossing into a cell of higher importance is split, whereas a particle crossing into a cell of lower importance undergoes Russian Roulette. In this way, particles from the source migrate toward the tally region. The user can also employ a mesh-based weight window (or “importance”) generator, where a mesh is

superimposed over the entire geometry of the problem; this causes an optimum performance function to be generated. This importance function is usually superior to anything an experienced user can guess for cell importances (especially when *thousands* of cells make up the problem, manually assigning an importance to each one becomes non-trivial). All regions in the problem are assigned a set of upper and lower weight window bounds. Particles with weights greater than the upper bound are split so that all split particles are within the window; particles with weights below the lower bound play Russian Roulette to increase their weight until they lie within the window or are killed [21]. This causes more particles with lower weight to drift toward the tally region.

POINT/RING DETECTOR

The use of a point detector (or a ring detector if the problem has axial symmetry) is a *partially deterministic method* where the random walk process is replaced by a deterministic process to move particles from one region to another. It is a necessity in situations where the analog random walk is inefficient. Often, the point is in a region far from the source in an area where it would otherwise be difficult to transport particles. It deterministically estimates the fluence at the specified point in the problem. At every collision site, the probability of a particle scattering toward the point detector is calculated. There are three factors that affect this probability: the distance between the collision site and the point/ring detector; the probability of scattering toward the point/ring detector, rather than in the original direction; and the optical thickness of material between the collision site and the point/ring detector. In this case the point detector was placed at the center of each 7.62 cm (3 in) diameter, 2.54 cm (1 in) thick

plastic nTOF scintillator. However, to eliminate cross-talk, only one point detector was used at a time. Also, since the bottom pig was 3° off axis as shown in Figure 2, a ring detector could not be used (the problem was not axially symmetric); a point detector was used instead.

DXTRAN

Like the point/ring detector, DXTRAN is a *partially deterministic* method. It stands for “deterministic transport,” and is a “next event estimator” which is used to deterministically transport the uncollided weight from collision and source points to a spherical surface, known as a DXTRAN sphere. Thus, source particles upon being born, or upon collision during their random walk, generate “pseudoparticles” which are *deterministically transported*, without collision, to the DXTRAN sphere. The random walk is then continued *inside* the sphere for these DXTRAN particles. If non-DXTRAN particles try to enter the DXTRAN sphere, they are killed (i.e., removed from the problem) to balance the particle weight contribution to the cells inside the sphere. In this way, one can obtain many particles in a small region of interest that would otherwise be difficult to sample. For this case, a DXTRAN sphere was made just to encompass each 7.62 (3in) diameter, 2.54 cm (1in) thick plastic nTOF scintillator. And similarly with using point detectors, only one DXTRAN sphere was used at a time to eliminate cross-talk between multiple spheres.

FORCED COLLISIONS

Forced Collisions is a *modified sampling method* which artificially increases the sampling of collisions in specified cells, generally those near a DXTRAN sphere and/or

point/ring detector. This method splits particles into collided and uncollided parts, where the collided part is forced to interact within the specified cell while the uncollided particle exits the cell without collision. In combination with a DXTRAN sphere and a point/ring detector, this method produces large numbers of collisions which are desirable to more efficiently approach the problem solution. For this model, the specified cell on the forced collisions card was the cell assigned to the actual nTOF plastic scintillator with a point detector located at its center, which was encompassed by a DXTRAN sphere.

IMPLICIT CAPTURE

Like Forced Collisions, implicit capture is a *modified sampling method*. When a particle collides, there is a probability that it is captured by the nucleus. In analog capture, the particle is killed with that probability. In implicit capture (also known as “survival biasing,” and “absorption by weight reduction”) the particle is never killed by capture; instead, its weight is reduced by the capture probability at each collision. In this way, no particles are lost to absorption, but absorption effects are properly accounted for. The advantage of implicit capture is that important particles are not killed after a great deal of effort has been expended to transport them long distances, and that when a particle has finally, against considerable odds, reached the tally region, it is not absorbed just before a tally contribution is made. Also, particles that lose energy through multiple collisions and are no longer considered useful, analog capture can efficiently get rid of them – the user can specify the energy at which analog capture

takes over. In fact, implicit capture is so powerful that it is one of two MCNP variance reduction options that is turned on by default. The other is Russian Roulette [5].

Using the above variance reduction methods, generally two runs were required to satisfy the requirements of a “good” calculation, namely, that the relative error on the point/ring detector tally (located at the center of the nTOF scintillators) were less than 5%, the Figure of Merit (FOM), or measure of efficiency, was maximized, and that all ten statistical checks in the output were passed. The Figure of Merit is defined as:

$$FOM = 1/R^2T \quad (5)$$

where T is the run time, and R is the relative error generated by the point/ring detector tally. For different VRTs, the one with the largest FOM is preferred.

VARIANCE REDUCTION CAVEATS

While some problems can only be solved by using variance reduction methods, the user should proceed cautiously when applying them. When they are used correctly they can greatly help the user produce a more efficient calculation. Used poorly, however, and they can result in a wrong answer with good statistics and few clues that anything is amiss. The user should proceed cautiously when applying VRTs. A few precautions a user should heed when using VRTs are the following:

- The user should err on the conservative side when using VRTs (some techniques are not recommended for the inexperienced user, such as forced collisions, point/ring detectors, and DXTRAN spheres).
- The output should be studied for peculiarities (large fluctuations, etc.)

- One of the key parameters for assessing the effectiveness of a VRT is the Figure of Merit (FOM) – generally the better the improvement of the FOM, the better is the VRT.
- Also, the FOM table should not be erratic; this indicates poor sampling. The FOM should rapidly approach a constant value (except for fluctuations early on in the simulation).

SMOOTHING THE RAW SIMULATED DATA

Once the variance reduction techniques listed above were implemented, and the output was examined to make sure the relative error on the point detector tally was < 5%, the FOM was maximized, and the ten statistical checks passed, the post-processing code was used to plot light output (MeVee) vs time (ns). An example of a plot produced is shown in Figure 11 for detector location “D” as indicated in Figure 1. It should be noted that this data indicated the largest amount of scattering seen in an nTOF signal for this type of experiment. Note that after the initial neutron peak there is a very large, second scattering peak. This was a model of the machine as shown in Figure 3. MCNP- PoliMi models were run at each axial detector location (“C” and “D” in Figure 1), each before and after the collimator was implemented, and will be compared with the experimental data in Chapter 6.

As can be seen in Figure 11, despite all the efforts with variance reduction to obtain as good a signal as possible at the detector, due to the complexity of the problem with large source-to-detector distances, and abundant scattering material throughout

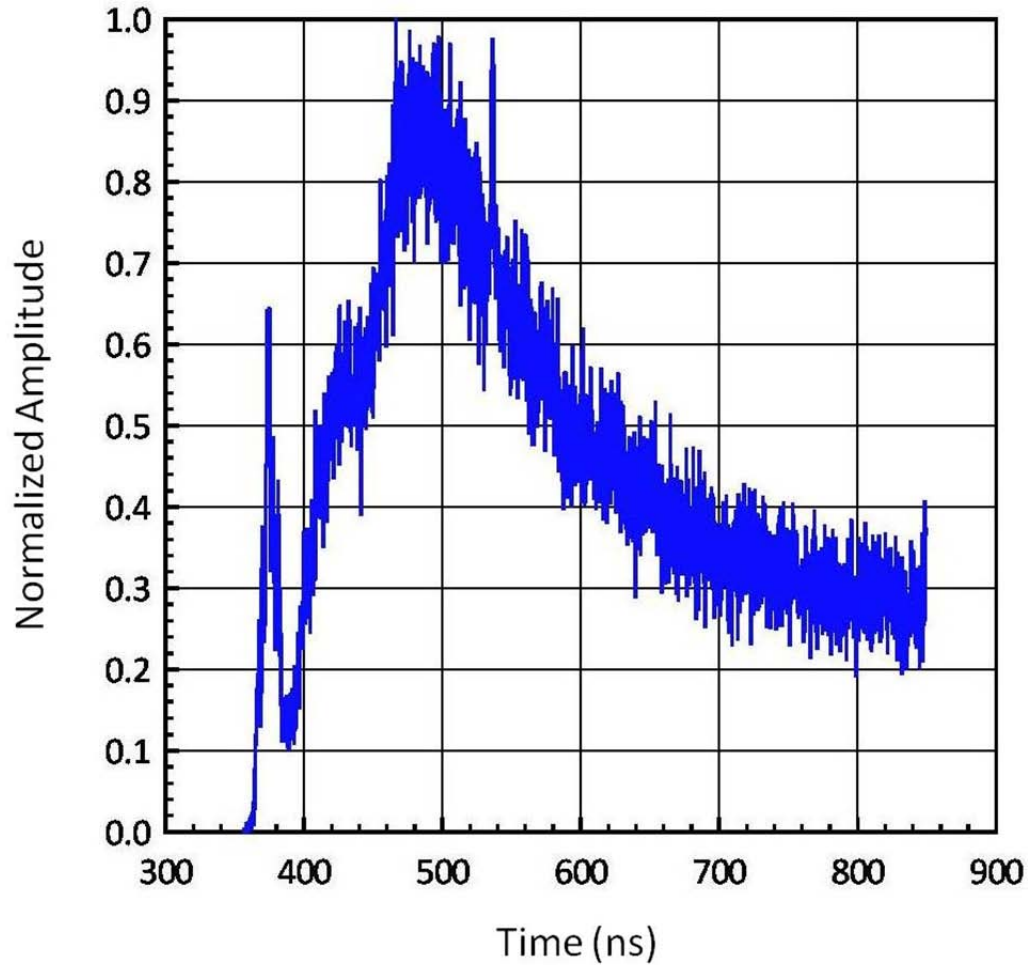


Figure 11. Output of the post-processing code for the largest amount of scattering seen in an nTOF signal for this type of experiment. Light output in MeVee is plotted vs time in ns. This particular case is for detector location “D” in Figure 1. Note that after the primary neutron peak there is a very large, second scattering peak.

the model, the raw simulated data is too noisy. To smooth out this noise, a Savitzky-Golay smoothing filter was used [22]. The advantage of this method is that it tends to preserve features of the distribution such as relative minima, maxima, and width, which are usually ‘flattened’ by other adjacent averaging techniques [23]. The raw simulated data before and after smoothing are shown in Figure 12.

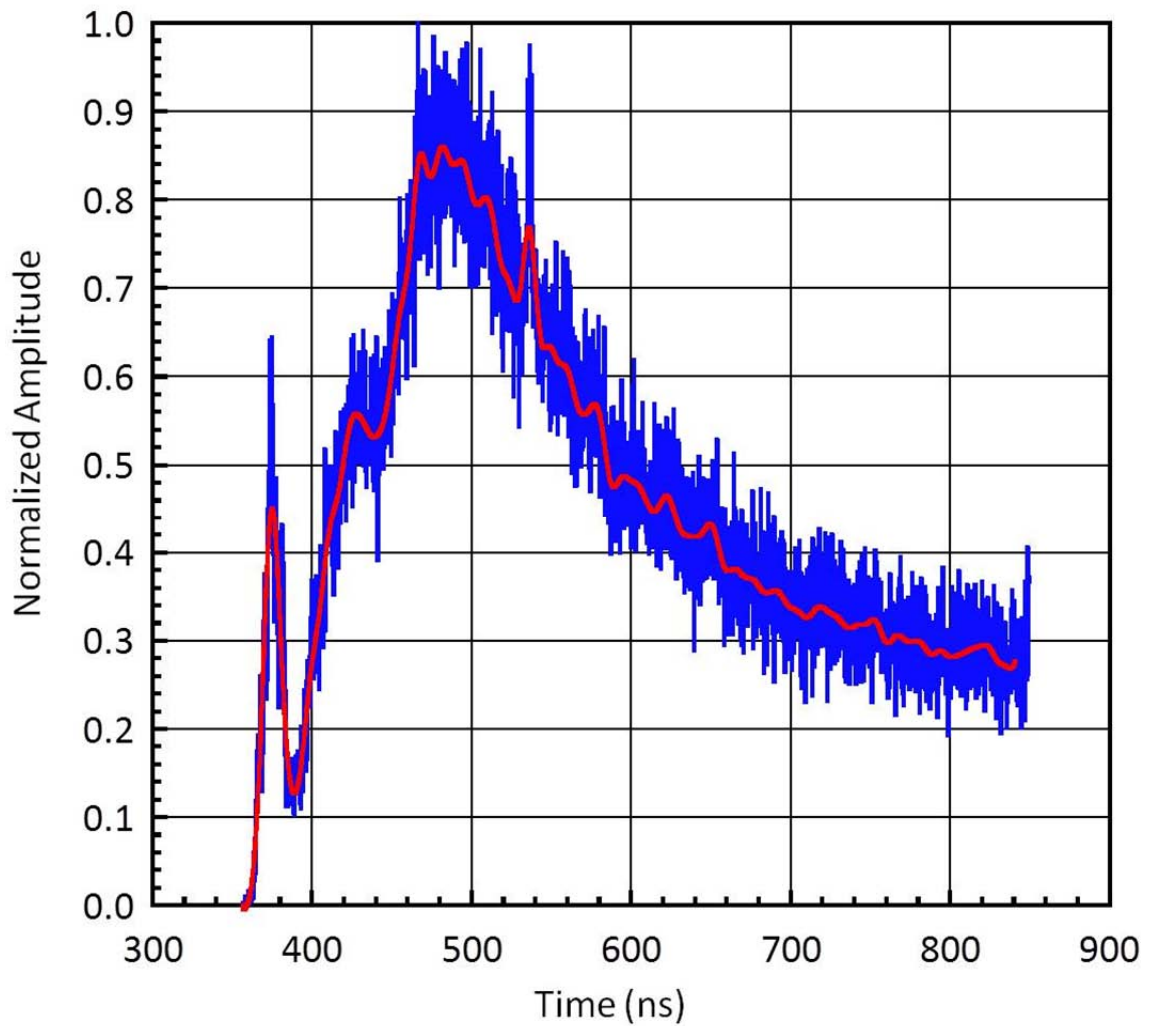


Figure 12. Despite using numerous variance reduction techniques to obtain the best signal possible at the detector, the raw simulated data from Figure 11 (blue) is still too noisy. The Savitzky-Golay smoothing filter was applied to help smooth out the noisy simulated data and is shown in red.

CHAPTER 6

CONVOLVING THE TIME RESPONSE

The next step was to “fold in” – or convolve – the actual time response of the detector with the post-processor output. This required another code to be written in MATLAB. The time response of the detectors used was found experimentally at the Idaho Accelerator Center (IAC) using their 15 MeV Linac producing a 50 ps photon beam [24]; (see also Appendix E). A plot of a detector time response is shown in Figure 13.

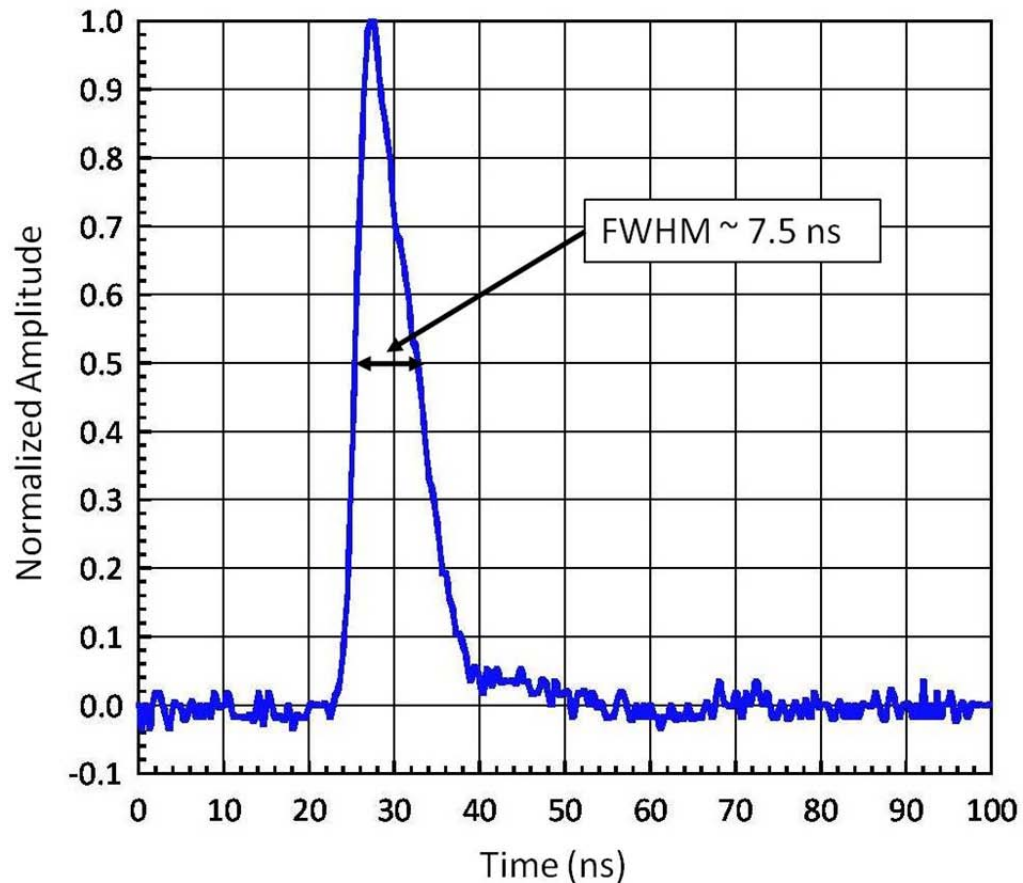


Figure 13. Time response of an nTOF detector found at the Idaho Accelerator Center (IAC). The FWHM is approximately 7.5 ns. This was made with 50 picosecond bursts of x-rays. It will be convolved with a neutron impulse response later in order to include both *timing* and *neutron impulse response information*.

The convolution of two functions $r(t)$ and $s(t)$, is denoted by:

$$(r \otimes s)_j \equiv \sum_{k=-\frac{M}{2}+1}^{\frac{M}{2}} s_{j-k} r_k \quad (6)$$

Typically s is a signal or data stream, and r is a response function of finite duration M . The effect of convolution is to smear – or broaden – the signal $s(t)$ in time according to the response function $r(t)$ [25].

BROADENING DUE TO TEMPERATURE AND TIME RESPONSE

In an “Ideal Case,” an nTOF detector at 809 cm (26.54 ft), location “D” in Figure 1, from a 4 keV DD fusion source would produce a FWHM according to:

$$Temp = 16578.1944 * \frac{(FWHM)^2}{D^2} \quad (7)$$

where Temp is in keV, D is in cm, and FWHM is in ns. Thus, the broadening due to temperature alone would be 12.57 ns for the parameters listed above. Then, folding in a time response of 7.5 ns, in quadrature [26], the FWHM becomes:

$$FWHM = \sqrt{(Temp\ FWHM)^2 + (Time\ Response\ FWHM)^2} \quad (8)$$

$$or, FWHM = 14.64\ ns$$

Broadening due to temperature and temperature *plus* time response is shown in Figure 14. Note how the time response broadens the signal and adds a small “tail” to the waveform. Also, the peak shifts to the right in time from 373.16 ns to 379.76 ns due to the convolution of the time response.

Another contributor to broadening in the real world is the thickness of scintillator *itself*. This is shown in Table II for plastic scintillator thicknesses ranging from 0.3175 cm (1/8") to 20.32 cm (8"). This data was obtained by running an "Ideal Case" – i.e., a scintillator of varying thickness at a distance of 809 cm from a 4 keV DD fusion source, and producing a waveform by the technique described herein. Also shown in the table is the broadening due to the convolution of the time response.

However, what role does *neutron scattering* play in the broadening of the detector response? It cannot be subtracted out in quadrature, since it is not a Gaussian phenomenon. Nevertheless, since it is entirely a function of how much structural and shielding material are near the detector, it would be unique in every location, and totally dependent on the local geometry. Therefore, the simplest approach would be to take the total FWHM and subtract out the FWHM due to temperature and time

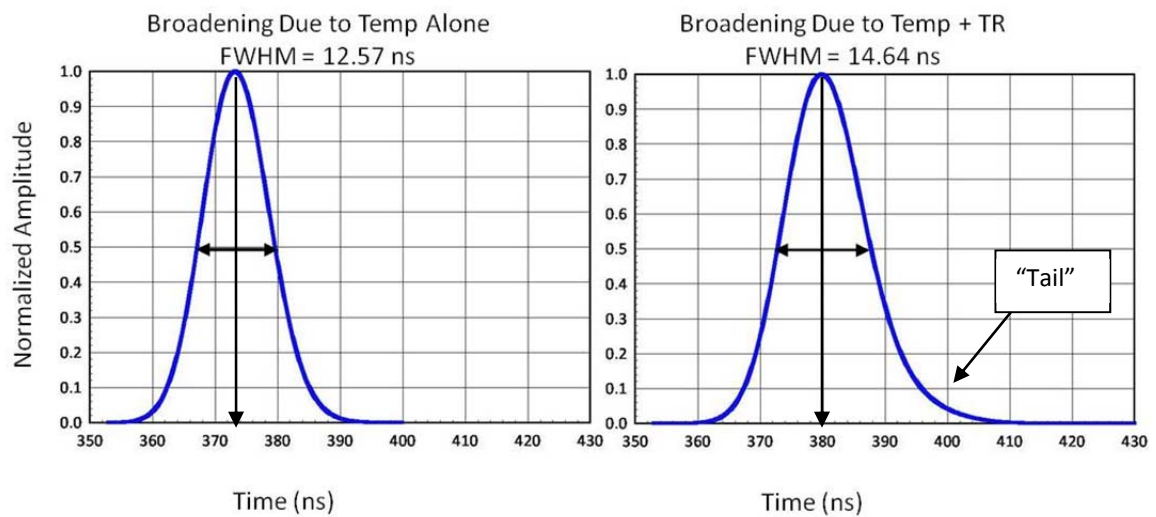


Figure 14. Broadening due to 4 keV temperature alone (right), and a 4 keV temperature and a time response of 7.5 ns (left). In the first case, the FWHM = 12.57 ns; in the second, the FWHM = 14.64 ns. Note that the peak shifts to the right in time from 373.16 ns (left) to 379.76 ns (right) due to the folding in of the time response, which broadens the signal, and produces a small "tail" (right).

response; the remainder would be the broadening due to neutron scattering at that particular detector location.

Table II.

Temporal Broadening due to Scintillator Thickness and Time Response

for a 4 keV DD Fusion Source placed at 809 cm.[†]

Thickness of Scintillator	Broadening due to Thickness (ns)	Broadening due to Time Response (ns) Ave: < 2.437 >
0.3175 cm (1/8")	---	2.394
1.27 cm (1/2")	0.03	2.425
2.54 cm (1")	0.03	2.43
5.08 cm (2")	0.08	2.518
7.62 cm (3")	0.33	2.441
10.16 cm (4")	0.53	2.418
15.24 cm (6")	0.83	2.425
20.32 cm (8")	1.03	2.441

[†]Ideally, for a 4 keV DD Fusion Source, broadening due to temperature alone is given by equation (7) above to be 12.57 ns, and broadening due to convolution with the time response is given by equation (8) above to be 14.64 ns.

COMPARING CALCULATIONS WITH EMPIRICAL DATA

Using the MATLAB code written for convolution, the time response was convolved ("folded in") with the post-processor output and compared with empirical data. In Figure 15, the calculated detector response is compared to shot z1217, with the machine in a configuration as shown in Figure 3. The plots are area normalized. The neutron source used in the MCNP-PoliMi model was a 4 keV DD Fusion Source.

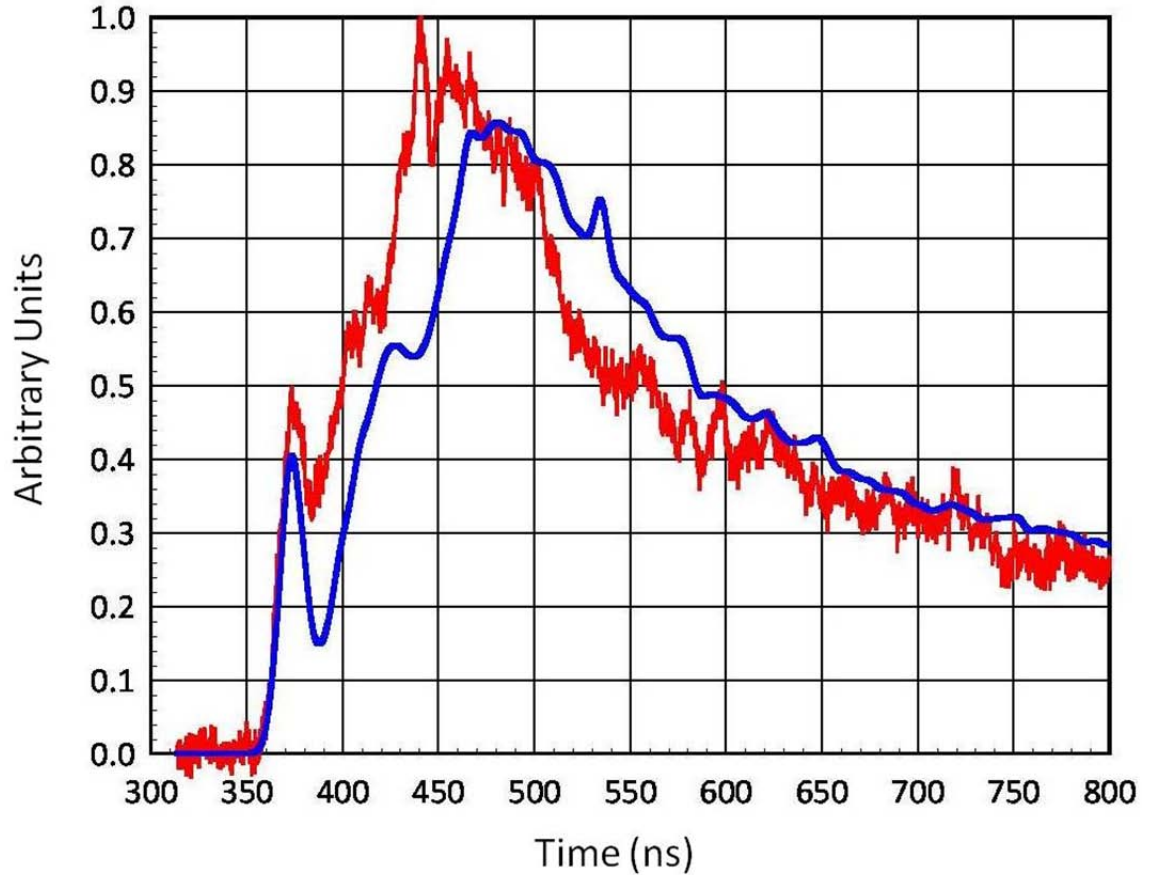


Figure 15. Area normalized comparison between shot z1217 without TIVAR 1000 Collimator (red) and MCNP-PoliMi model with folded-in time response for a 4 keV DD fusion source (blue) for a detector located at “D” in Figure 1. The same features can be observed: a primary neutron peak followed by a very large, second scattering peak.

A close up of the neutron peak from shot z1217 at detector location “D” in Figure 1 is compared to the model in Figure 16 below. The model shows a full width at half maxima of 16.38 ns. A FWHM cannot be extracted from the data due to the large, second scattering peak. Both plots are area normalized.

For the nTOF detector located at “C” in Figure 1, an MCNP-PoliMi model produced a neutron detector response and the detector time response was folded in as described above. A plot of the MCNP-PoliMi model compared with the actual empirical

data for the nTOF detector located at “C” for shot z1217 is shown in Figure 17. As can be seen, there is better separation between the primary neutron peak and the secondary scattering peak compared to Figure 15. Also, the neutron peak has a greater amplitude relative to the scattering peak. Both plots are area normalized.

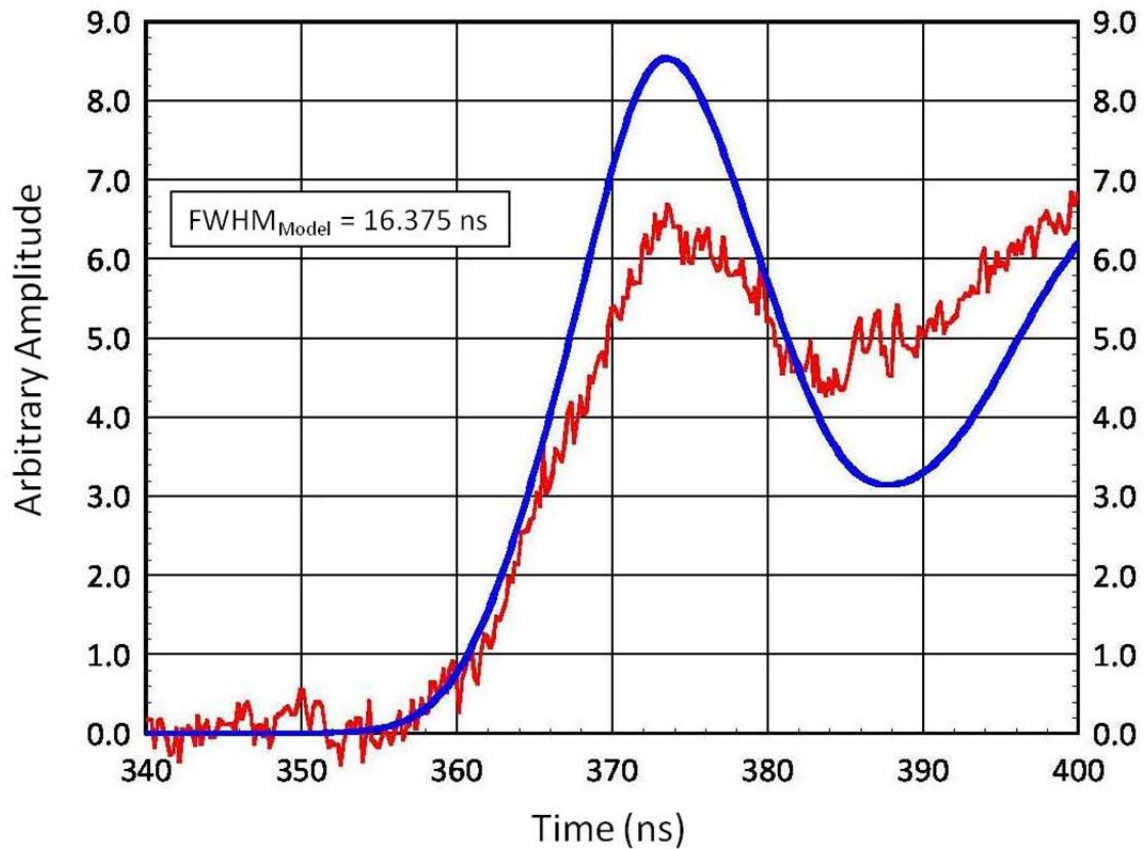


Figure 16. Close-up of the primary neutron peak in Figure 15, for the bottom nTOF detector located at "D" in Figure 1. The model was run at a temperature of 4 keV, and its full width at half maxima is 16.38 ns. A FWHM from the data cannot be extracted due to the large, second scattering peak following the neutron peak.

A close up of the neutron peak for shot z1217 located at “C” in Figure 1 is compared to the model in Figure 18. The FWHM of the data is 14.89 ns, while the FWHM of the model is 15.11 ns. Both plots are area normalized.

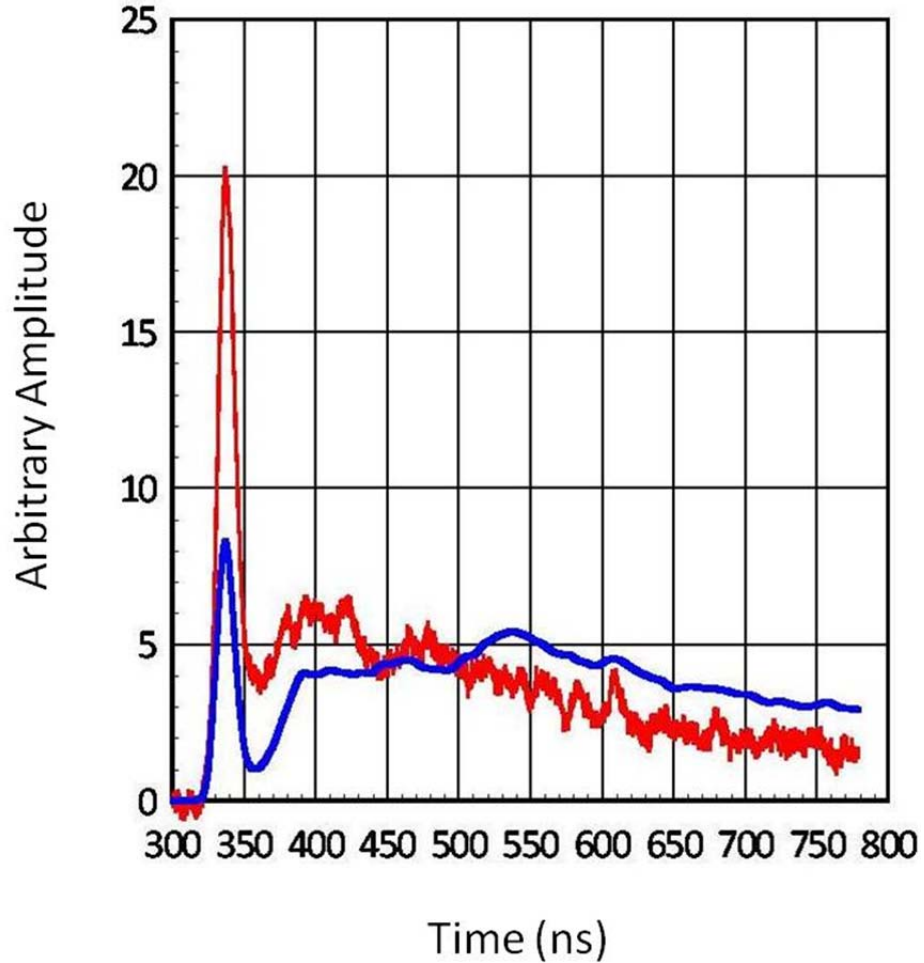


Figure 17. Area normalized comparison between shot z1217 without Tivar Collimator (red) and MCNP-PoliMi model with folded-in time response for a 4 keV DD fusion source (blue) for a detector located at “C” in Figure 1. There is better separation between the primary neutron peak and the second scattering peak than shown in Figure 15. Also, the neutron peak has a greater amplitude relative to the scattering peak than that shown in Figure 15.

To reduce the second scattering peak seen in Figure 17 for the detector located at “C” (in Figure 1) and to lessen the second scattering tail seen in Figure 15 for the other detector located at “D” (in Figure 1), a collimator made of UHMW TIVAR 1000 was built and placed under TCC as seen in Figure 19. This material was chosen over regular polyethylene because it does not outgas under vacuum [27]; (see also Appendix F). The collimator was 25.4 cm (10 in) long and had a tungsten insert on axis serving as a

gamma ray collimator for the intense bremsstrahlung background. The length of 25.4 cm (10 in) was chosen to be manageable to install; also MCNPX calculations showed that that length would attenuate DD neutrons by approximately a factor of 1000.

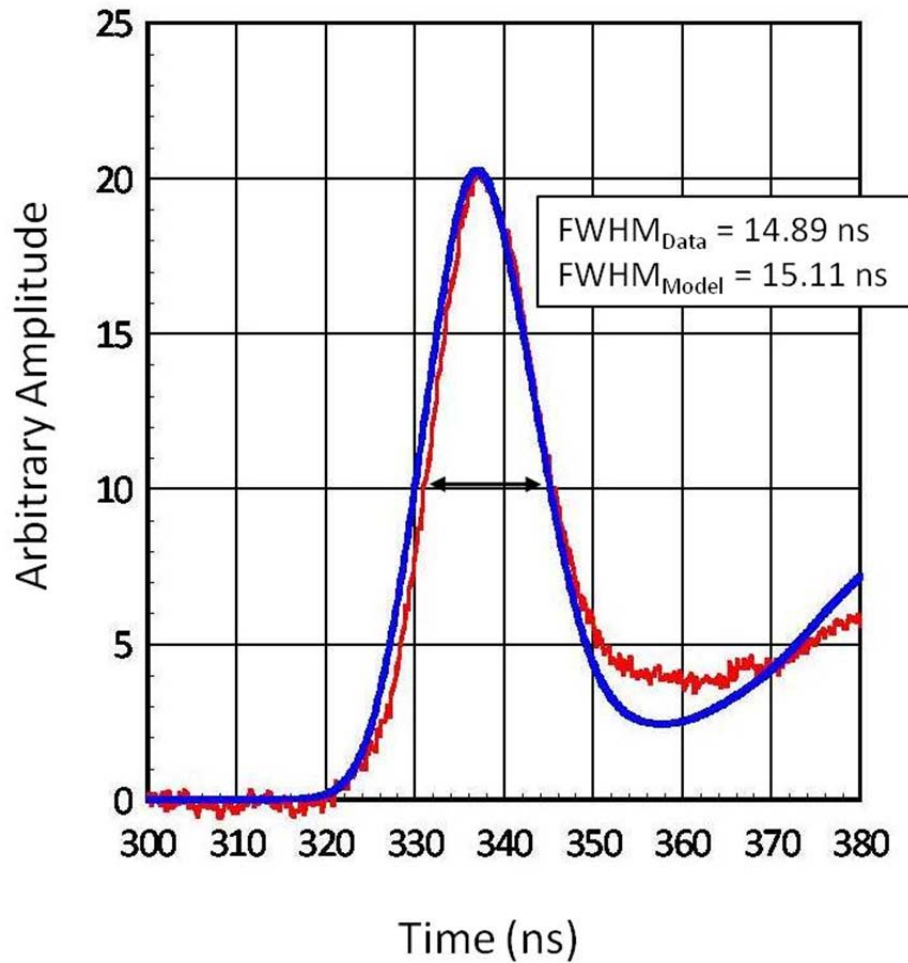


Figure 18. Close-up of the primary neutron peak in Figure 17, for the top nTOF detector located at “C” in Figure 1. The model was run at a temperature of 4 keV, and its full width at half maxima is 15.11 ns, while the data from shot z1217 has a full width at half maxima of 14.89 ns. Both plots are area normalized.

The exit aperture on the collimator was 7.62 cm (3 in). When projected downward, the collimator would cast a “shadow” all the way down to the basement floor, 880.76 cm (28.9 ft) below the pinch (TCC). This is shown in Figure 20. With the pig being 3 degrees off-axis, this made both nTOF detectors just fit inside the collimator

“cone,” as shown in Figure 21. However, it was hoped the collimator would reduce neutron scattering off the elevator floor that may have been contributing to the second scattering peak for the nTOF detector located at “D” in Figure 1 (i.e., the detector closest to the floor) as seen in Figure 6.

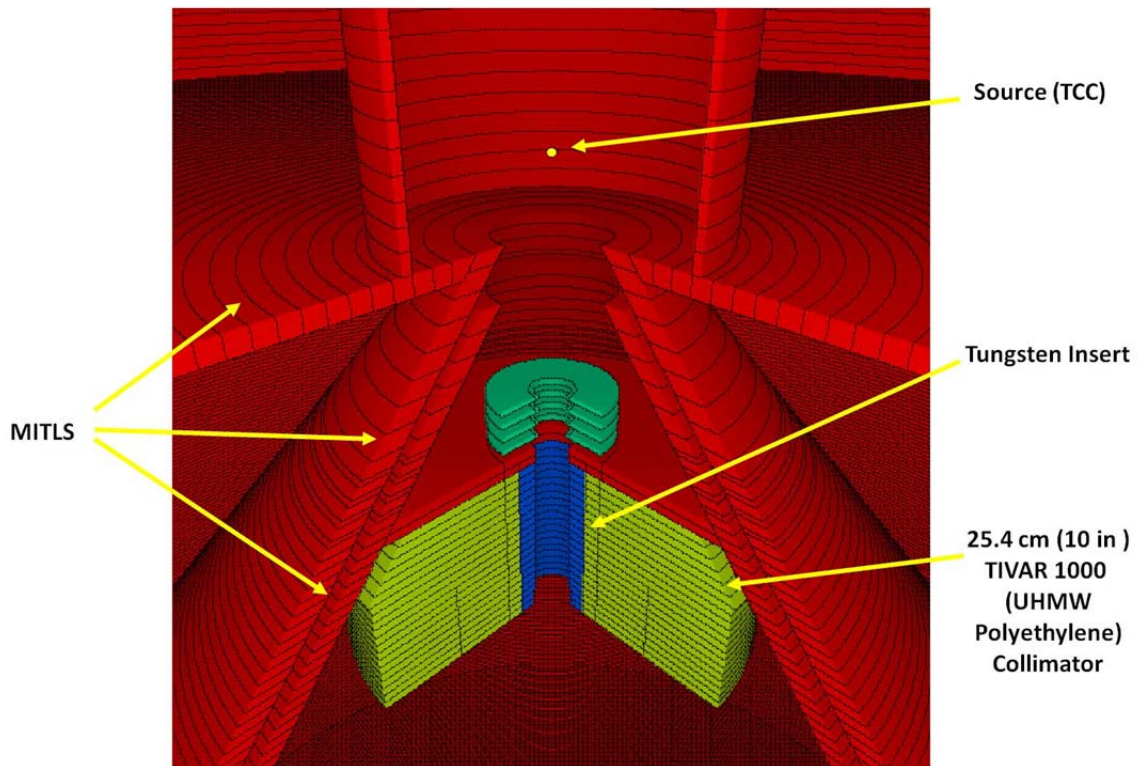


Figure 19. A closer view of the UHMW TIVAR 1000 collimator incorporated into the machine on neutron producing shots in order to help “clean up” neutron signals. MCNPX calculations showed that its length of 25.4 cm (10 in) would attenuate DD neutrons by approximately a factor of 1000. The tungsten insert is serving as a gamma ray collimator.

A plot of an MCNP-PoliMi model with the collimator in place, and the detector response convolved with the calculated signal (blue) compared to shot z1549 when the collimator was fielded on the machine (red) is shown in Figure 22. As can be seen, use of the collimator greatly reduced the second scattering peak and produced a much

greater amplitude of the primary neutron signal relative to the second peak as compared to Figure 15.

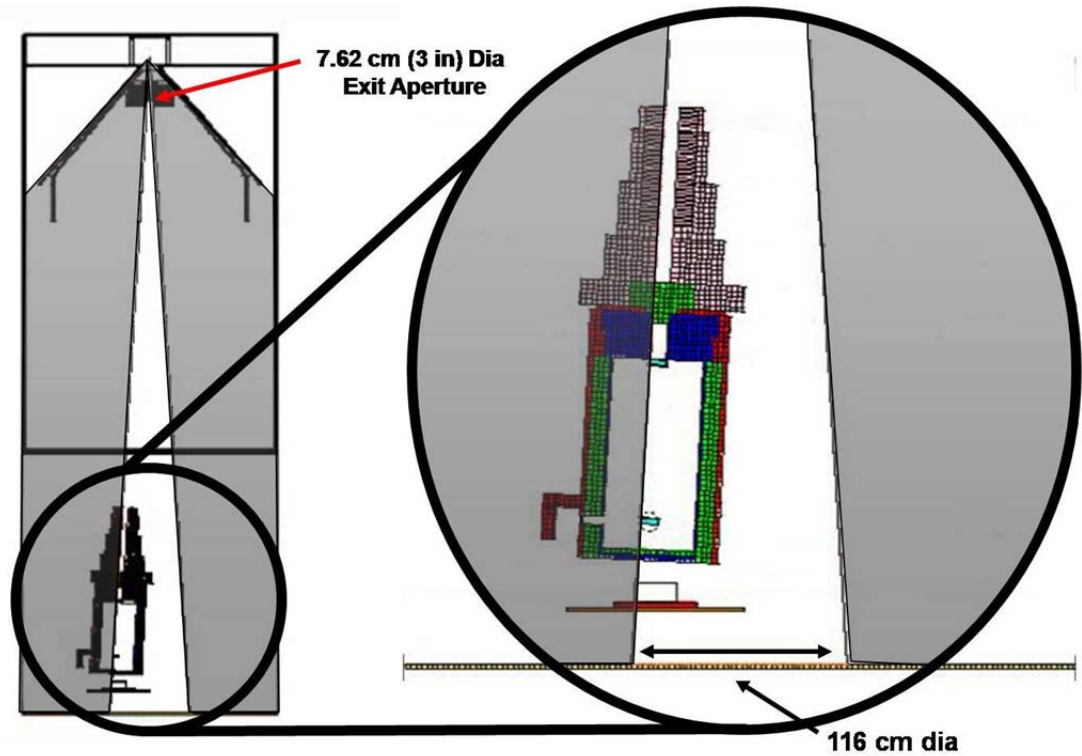


Figure 20. “Shadow” of TIVAR 1000 Collimator. With a 7.62 cm (3 in) diameter exit aperture growing to a 116 cm (45.7 in) diameter spread at the basement floor 880.76 cm (28.9 ft) below TCC.

A close up of the neutron peak for shot z1549 located at “D” in Figure 1 is compared to the model in Figure 23. The FWHM of the data is 12.75 ns, while the FWHM of the model is 11.84 ns. The model was run at a temperature of 2 keV for a DD fusion neutron source. Both plots are area normalized.

For the top nTOF detector located at “C” in Figure 1, a plot of its MCNP-PoliMi model with folded in time response (blue) is compared with shot z1549 for a fielded detector in the same location (red) in Figure 24. As can be seen, the effect of the collimator was to virtually eliminate the second scattering tail that was seen in Figure 17

(before the collimator was added). A close-up of the neutron scattering peak is shown in Figure 25. The full width at half maxima for the data is 12.70 ns, while the full width at half maxima for the model is 11.20 ns. Of note is that the temperature of the actual experiment is unknown, while the model was run with a 2 keV DD fusion neutron source.

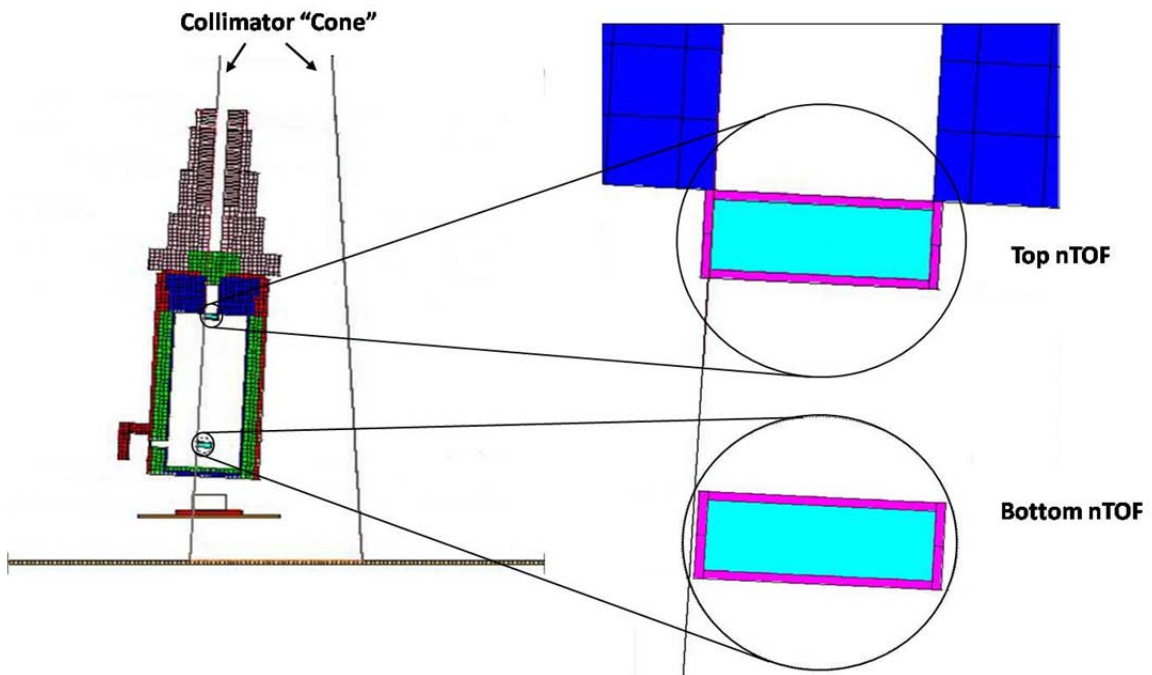


Figure 21. With the pig aligned 3 degrees off-axis, the collimator “cone” just encompassed both detectors. However, it was still hoped that the addition of the collimator would reduce neutron scattering off the elevator floor that may be contributing to the second scattering peak seen in Figure 15.

As can be seen from Figures 23 and 25, collimation is essential to produce “cleaner” neutron signals. It will be shown later that it does indeed reduce shallow-angle scattering in the neutron peak, and it helps eliminate the bulk of scattering arriving later in time. As shown by the “shadow” in Figure 20, neutrons removed early

in time by the collimator near the source therefore cannot arrive later in time at the detectors by scattering.

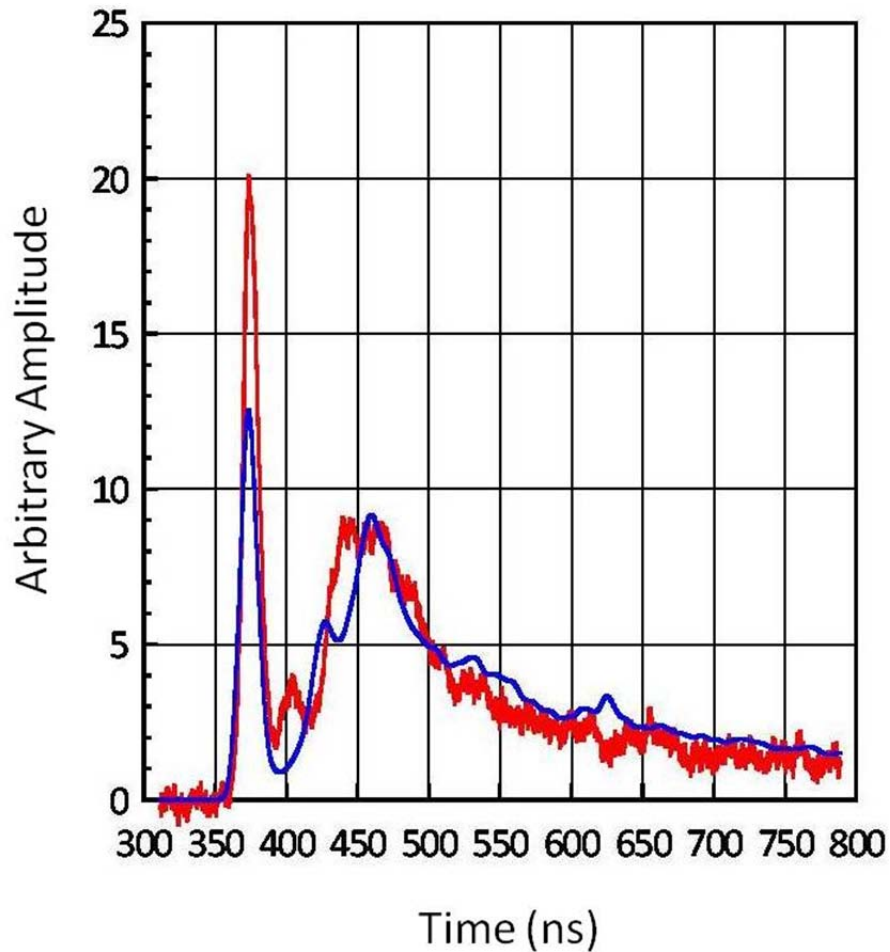


Figure 22. Area normalized comparison of shot z1549 (red) for detector at location “D” in Figure 1 with TIVAR 1000 Collimator in place and MCNP-PoliMi model with folded in time response of 7.5 ns (blue). Use of the collimator greatly reduced the second scattering peak and produced a much greater amplitude of the primary neutron signal compared to the second peak as compared to Figure 15.

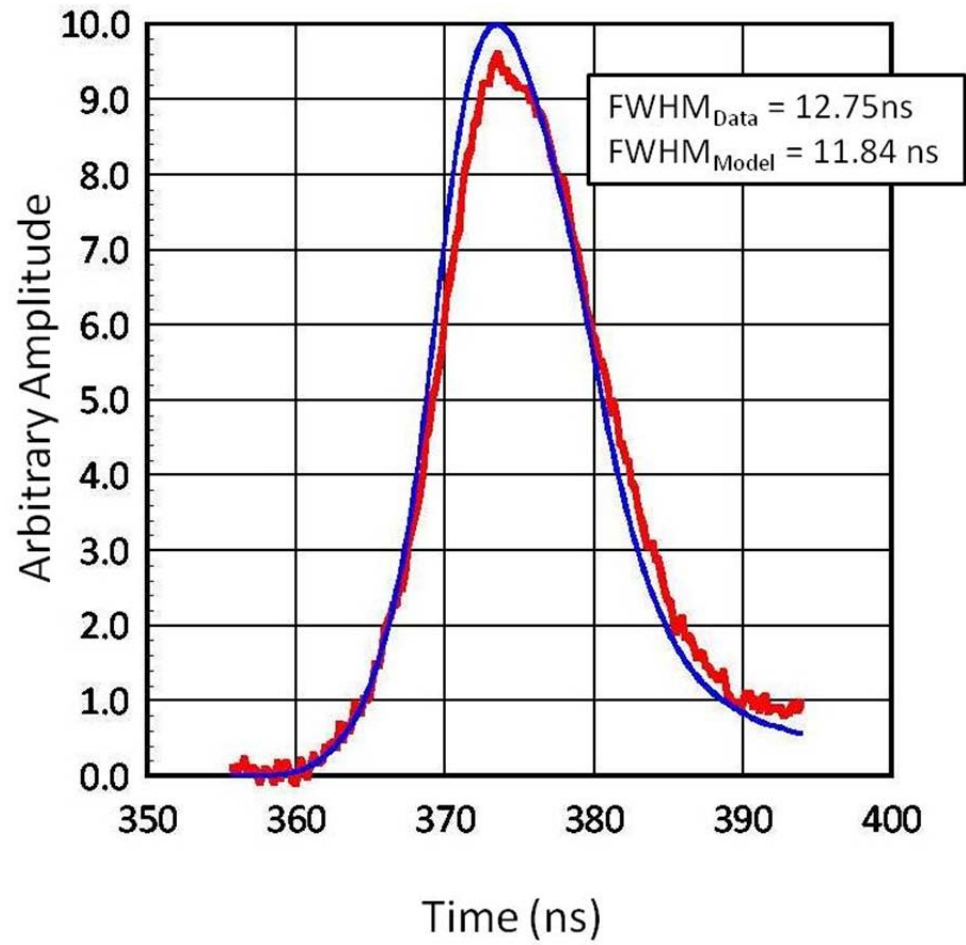


Figure 23. Close-up of primary neutron peak in Figure 22, for the bottom nTOF detector located at “D” in Figure 1. The full width at half maxima of the data is 12.75 ns, while the full width at half maxima for the model is 11.84 ns. The model was run with a 2 keV DD fusion neutron source.

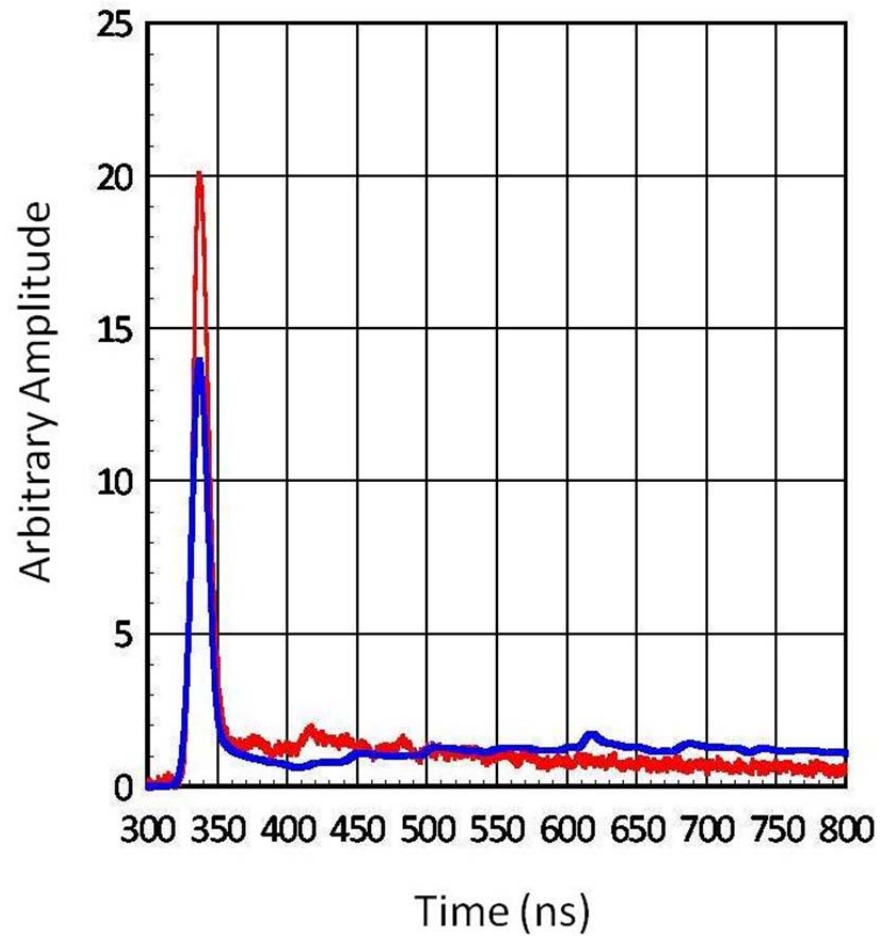


Figure 24. Area normalized comparison of shot z1549 (red) for detector at location “C” in Figure 1 with Tivar 1000 Collimator in place and MCNP-PoliMi model with folded in time response of 7.5 ns (blue). The effect of the collimator was to virtually eliminate the second scattering tail that was seen in Figure 17.

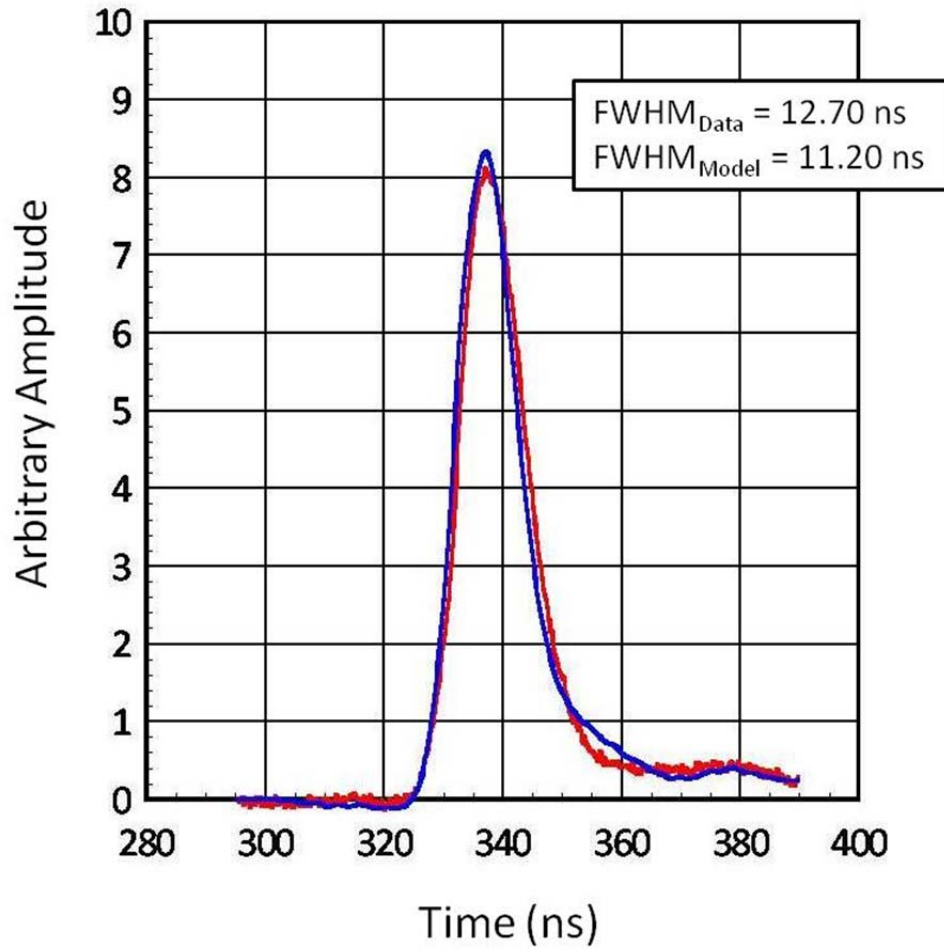


Figure 25. Close-up of primary neutron peak in Figure 21, for the top nTOF detector located at "C" in Figure 1 with the TIVAR 1000 Collimator in place. The full width at half maxima for the data is 12.70 ns, while the full width at half maxima for the model is 11.20. The model was run with a temperature of 2 keV DD fusion neutron source.

CHAPTER 7

DECONVOLVING THE TIME RESPONSE FROM THE SIMULATED DATA

It was shown above that a detector's intrinsic time response will broaden the detector's signal – in effect, it “smears” the data in time to some degree. To further analyze the data, however, this time response must be deconvolved – or “unfolded” – from the data. Deconvolution is a process of *undoing* the smearing in the data that has occurred due to the influence of a known response function. The equation for deconvolution is the same as that for convolution, namely equation (6), except that now the left hand side is taken to be known, and (6) is to be considered as a set of N linear equations for the unknown quantities s_j . This can be accomplished using Fast Fourier Transforms. First, the transform of the signal (which is convolved with the response function) is taken. Next the transform of the response function is taken. The transform of the signal is now *divided* by the transform of the response – this gives the transform of the deconvolved signal. The last step is to take the inverse FFT to finally obtain the raw signal.

To make sure the process was correct, the time response in Figure 13 was deconvolved from the MCNP-PoliMi model with folded-in time response for a 4 keV DD fusion source (blue), shown in Figure 15. After deconvolving, the result was compared with the smoothed calculated data shown in Figure 12 (red) and will be discussed below. A set of codes from *Numerical Recipes* was used to accomplish this [25].

Prior to attempting Fast Fourier Transforms, the signal and time response have to be “prepared.” The number of points in the signal must be an integer power of 2, and “zero-padded” (i.e., extended with zeros) at its extreme end in time. The amount of zero-padding at the end of the data must equal the number of data points in region “A” or “B” in Figure 27 – *whichever is larger*. This is shown in Figure 26 below.

The time response has to be placed in “wrap-around order,” meaning the data is considered as being wrapped around a cylinder with the ends touching – this means

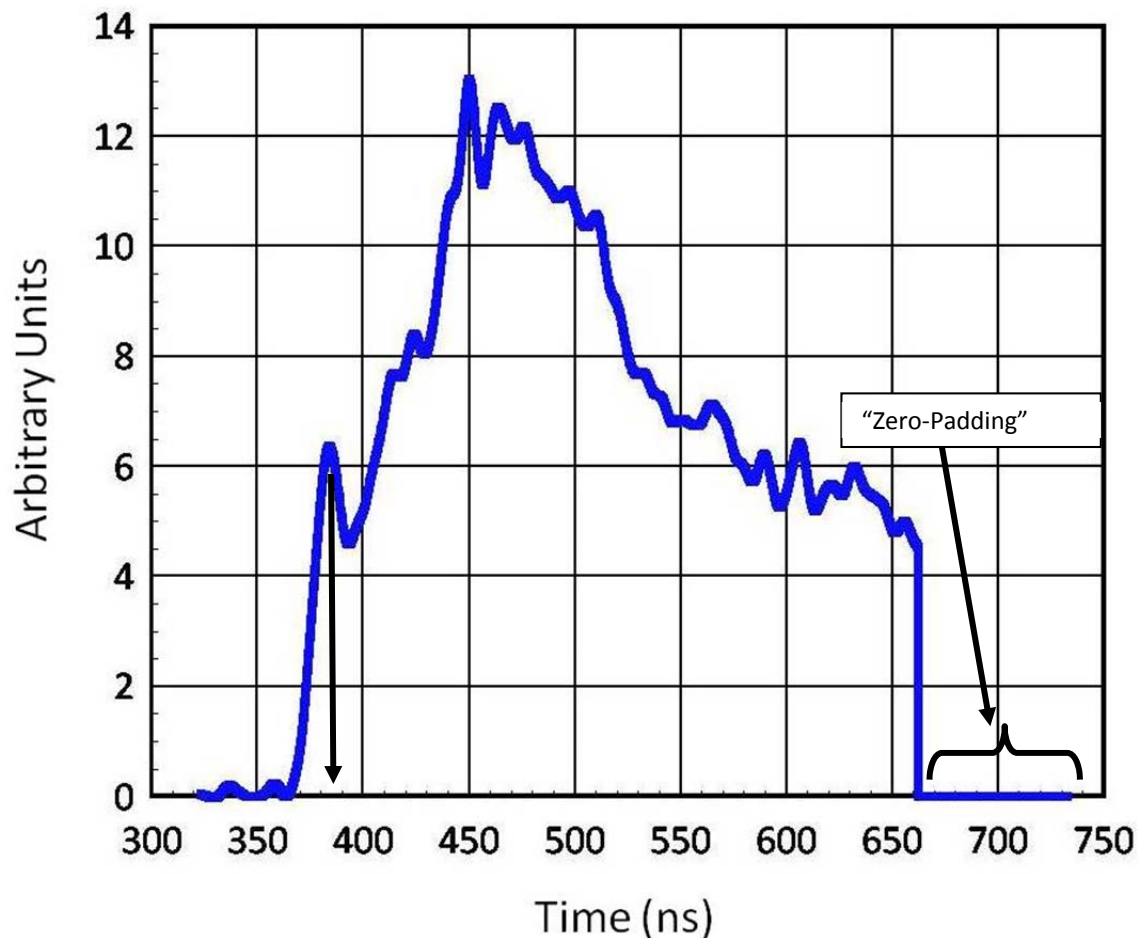


Figure 26. Preparation for the signal prior to taking Fast Fourier Transforms. This is the empirical data from shot z1217. The total number of points in the signal must be an integer power of 2, and “zero-padded” – or extended with zeros at its extreme end in time. The amount of zero padding must equal the number of points in region “A” or “B” in Figure 27 – *whichever is larger*. (Note that the neutron peak is at 383.13 ns – see arrow.)

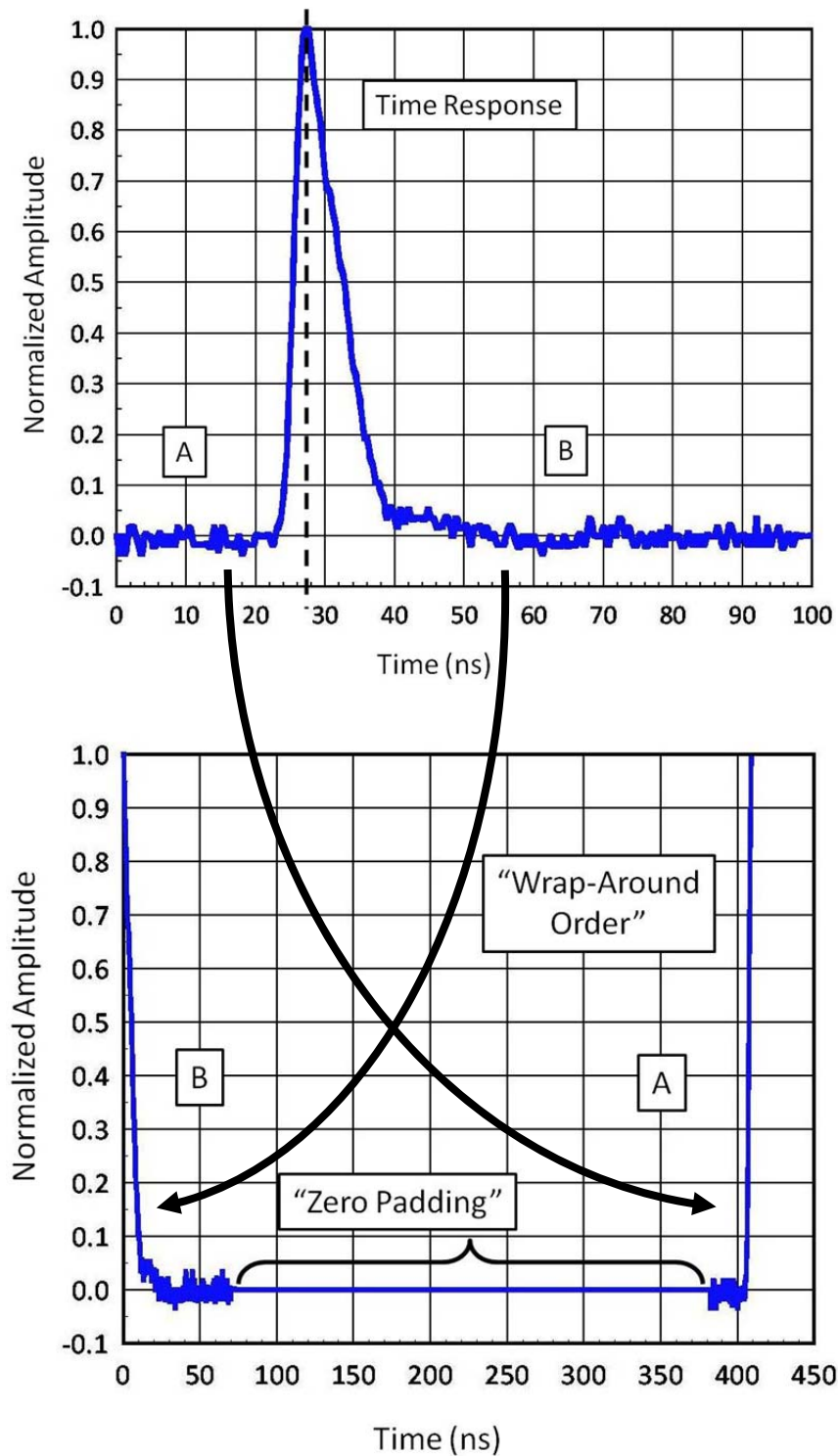


Figure 27. “Wrap-Around Order.” First the time response (above, and the same as shown in Figure 13), is cut in half at its peak. Then each side of the time response is *flipped left-for-right* (see arrows), then “zero-padded” in the middle. The total number of points, M , can be any odd integer less than or equal to N , the number of points in the data, which must be an integer power of 2.

that a large center section in the middle of the data, is zero, with nonzero values clustered at the two extreme ends. This is shown in Figure 27.

Once the data and the response function have been prepared properly, the deconvolution can be accomplished by Fast Fourier Transforms. A plot of the smoothed, calculated data (blue) is compared with the deconvolved fit (red), and the smoothed, deconvolved fit (green) is shown in Figure 28. The blue and green traces fall neatly on top of each other, showing good agreement.

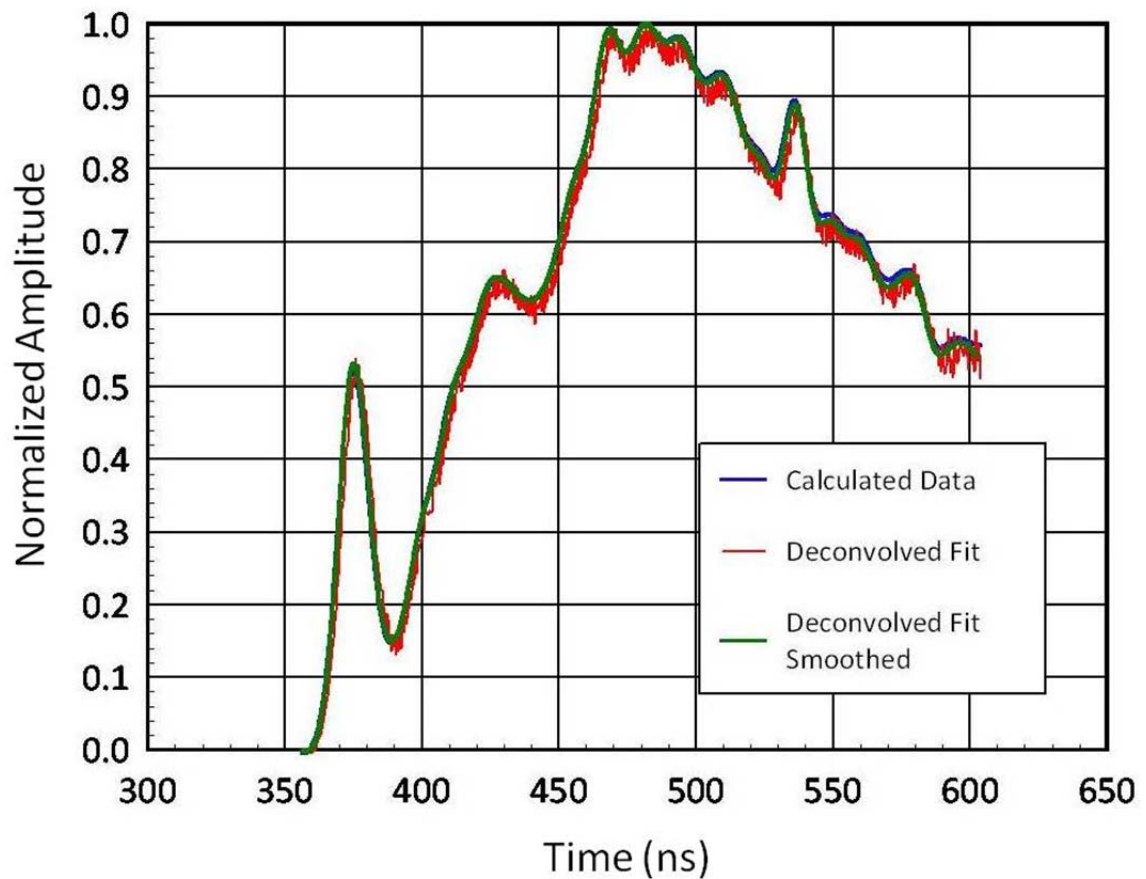


Figure 28. The smoothed calculated data (blue, also shown in Figure 12 with a red trace) is compared to the deconvolved fit using Fast Fourier Transforms (red). The deconvolved fit is smoothed (green) and can be seen laying on top of the calculated data, showing good agreement. Both blue and green traces have been smoothed with the Savitsky-Golay smoothing filter.

CHAPTER 8

CONVOLVING A NEUTRON IMPULSE RESPONSE WITH THE KNOWN TIME RESPONSE

Using the techniques described herein, a *monoenergetic* source of neutrons of 2.45 MeV were run with a 2.54 cm (1 inch) scintillator placed at 809 cm. The resulting waveform can be described as the *calculated neutron impulse response* for the scintillator, and is shown in Figure 29 below. The shape of the waveform from 374.51 ns (where it begins) down to 375.71 ns (both indicated by arrows) is a time span of 1.2 ns.

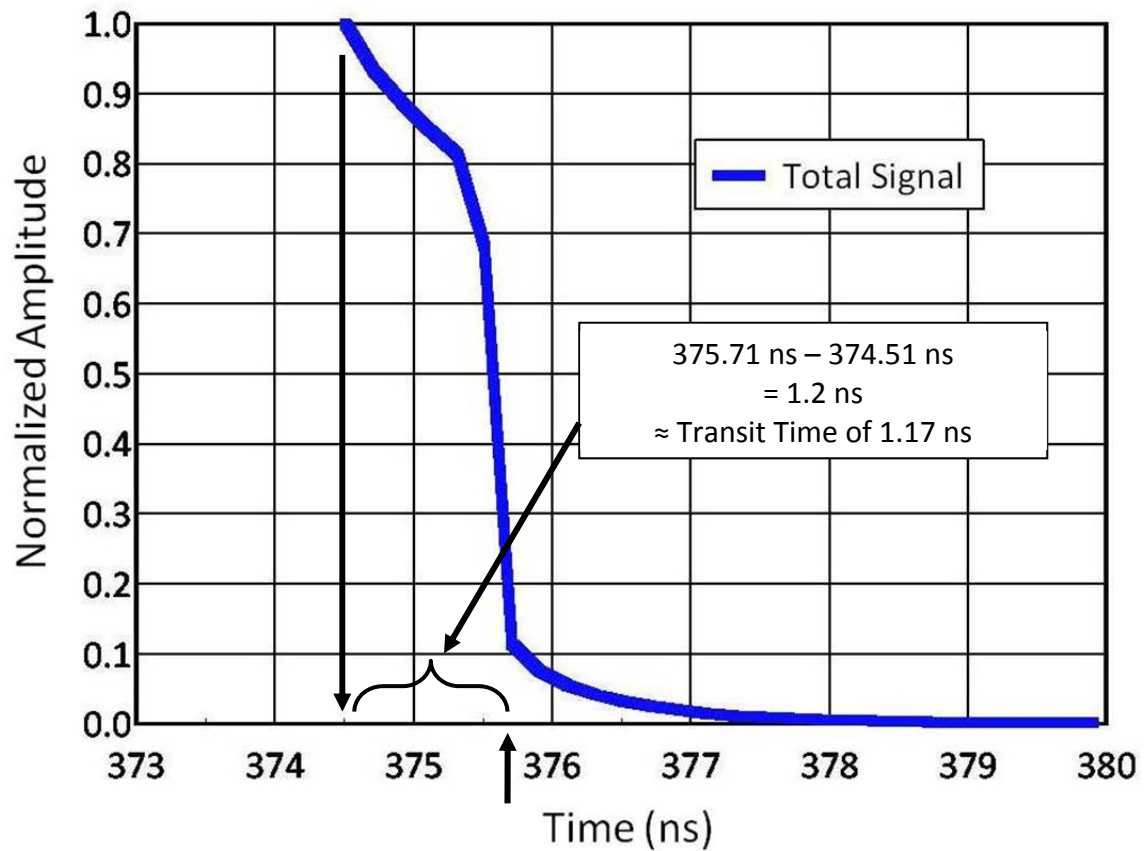


Figure 29. The neutron impulse response for a 2.54 cm (1 inch) scintillator placed 809 cm from a monoenergetic source of 2.45 MeV DD neutrons. The region in time indicated by the bracket is 1.2 ns, which is due to the transit time of a 2.45 MeV neutron traversing the scintillator. The curved portion of the waveform which follows is due explicitly to secondary scattering in the scintillator, and is described in Figure 30.

This value of 1.2 ns correlates to the *transit time* of a 2.45 MeV neutron passing through a 2.54 cm (1 inch) scintillator, and can be found by:

$$KE = \frac{1}{2}mv^2 \quad (9)$$

Substituting 2.45 MeV for *KE*, letting *m* = *m*₀, and multiplying by *c*²/*c*² gives:

$$2.45 \text{ MeV} = \frac{1}{2} \frac{v^2}{c^2} m_0 c^2 \quad (10)$$

Solving for *v/c*:

$$\frac{v}{c} = \sqrt{\frac{(2)(2.45 \text{ MeV})}{m_0 c^2}} \quad (11)$$

Letting *c* = 2.9979E10 cm/sec, and *m*₀*c*² = 939.5653 MeV for a neutron and solving for *v*:

$$v = \sqrt{\frac{(2)(2.45 \text{ MeV})}{939.5653 \text{ MeV}}} (2.9979E10 \frac{\text{cm}}{\text{sec}}) \quad (12)$$

v becomes:

$$v = 2.166E09 \frac{\text{cm}}{\text{sec}} (\frac{1 \text{ sec}}{10^9 \text{ ns}}) \quad (13)$$

Thus, the velocity of a 2.45 MeV neutron is:

$$v = 2.166 \text{ cm/ns} \quad (14)$$

And the transit time through a 2.54 cm (1 inch) thick scintillator becomes:

$$\text{Transit Time} = \frac{2.54 \text{ cm}}{2.166 \text{ cm/ns}} \quad (51)$$

or:

$$\textit{Transit Time} = 1.17 \textit{ ns}$$

(16)

PRIMARY AND SECONDARY NEUTRON SCATTERING

One of the versatile features of the collision data output table (Table I), is that it contains so much germane information. As noted in this work, the incident particle, target nucleus, energy deposited and time of the event were used to model the nTOF detector response. Other information in the table includes the *number of scatterings* which have occurred. Using this information, Figure 29 can be further analyzed in terms of *primary and secondary neutron scattering*. In this context, primary scattering refers to the number of scatterings in Table I to be equal to one, and secondary scattering refers to the number of scatterings in Table I to be greater than one. The post-processing code was easily modified to plot the light output due only to primary scattering in one case (i.e., number of scatterings = 1), and only secondary scattering (i.e., number of scatterings > 1) in the other. The result is shown in Figure 30. The total signal (blue) is the same as that shown in Figure 29. The green, however, shows only the light output produced by primary scattering, and the red shows only the light output produced by secondary scattering. If both signals are summed (red and green), they equal the total signal (blue). In the span of transit time shown in Figure 30 of 1.2 ns, 85.6 % of light output is due to primary scattering, and 14.4% of light output is due to secondary scattering (this was done by summing amplitudes of the total signal, primary and secondary scattering and determining the contribution of each). Upon arriving at

the scintillator, a neutron may collide with a hydrogen atom on the front face of the scintillator (in which case, the transit time is much less than 1.2 ns), or it may traverse through the scintillator and collide with a hydrogen atom in the middle (in which case, the transit time would be $1.2\text{ ns}/2 = 0.6\text{ ns}$), or it may interact at the back face of the scintillator (in which case, the transit time would be 1.2 ns). Of note in Figure 30 is that after 375.71 ns the light output produced is due to secondary scattering only, since the green trace (primary scattering) drops to zero and the red trace (secondary scattering) lies on top of the blue trace (i.e., the total signal).

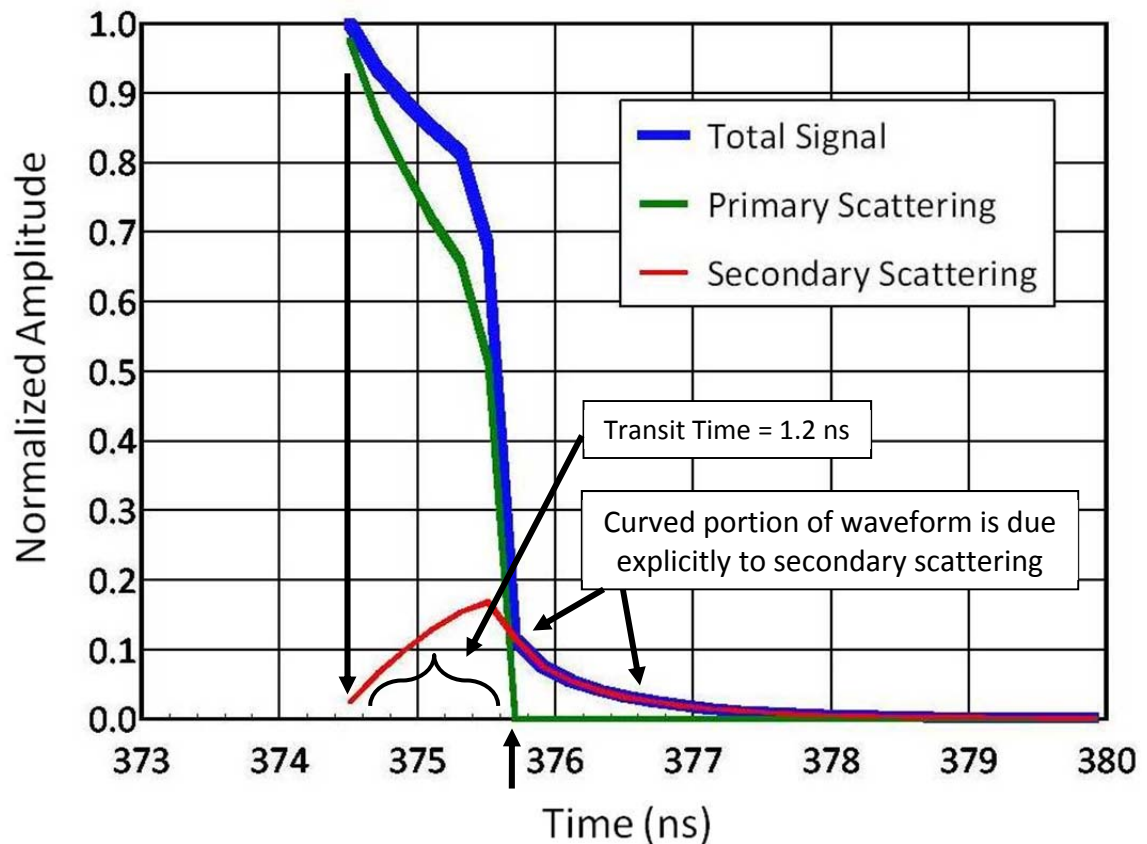


Figure 30. The neutron impulse response divided up into its component parts: primary and secondary scattering. In the span of the transit time of 1.2 ns, 85.6% of the light output is produced by primary scattering, while 14.4% of the light output is produced by secondary scattering. After 1.2 ns of transit time, the green trace (primary scattering) drops to zero and all light output produced is due to secondary scattering only.

To analyze the data as correctly as possible, it was then necessary to convolve the neutron impulse response (Figure 29) with the time response (Figure 13). The reason to include both these waveforms is that they each contain information necessary for a “total” signal. Figure 13, the time response, was found by pulsing x-rays with a 50 picosecond width into the nTOF detector at the Idaho Accelerator Center (IAC) using their 15 MeV short pulse Linac [24]; (see also Appendix E). This provided *timing information* due to impinging x-rays, but it did not provide any *neutron impulse information*. Therefore, the monoenergetic 2.45 MeV neutron impulse response (Figure 29) is necessary to be included, which is why it was convolved with the time response and shown in Figure 31 below.

The FWHM of 7.607 ns in Figure 31 compares favorably with finding it analytically in quadrature:

$$FWHM = \sqrt{(7.5 \text{ ns})^2 + (1.2 \text{ ns})^2} \quad (17)$$

The full width at half maxima of the monoenergetic neutron impulse response convolved with the time response becomes:

$$FWHM = 7.60 \text{ ns} \quad (18)$$

Once the neutron impulse response was convolved with the time response, it was then necessary to find the *time delay* -- i.e., the delay from neutrons impinging on the face of the scintillator to the electronic signal coming out of the base of the photomultiplier tube. This consists of three components: (1) the average transit time of a 2.45 MeV neutron through a 2.54 cm (1 inch) scintillator (which is found from the value above); (2) the transit time of light produced in the scintillator that travels through

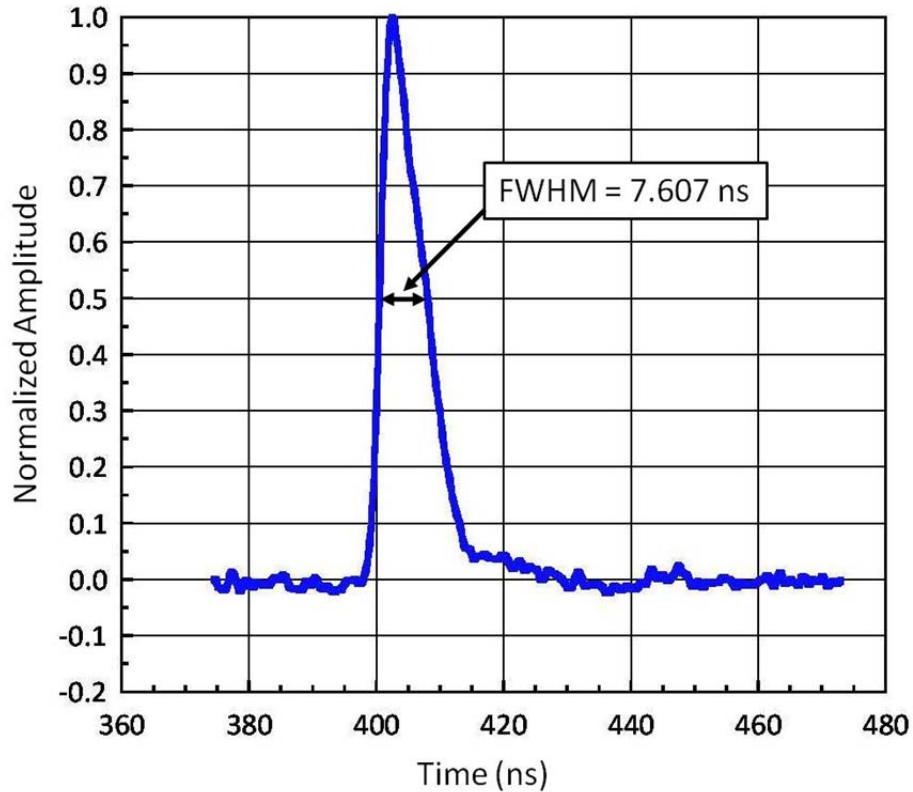


Figure 31. The convolution of the neutron impulse response (Figure 29) with the time response (Figure 13) found at the Idaho Accelerator Center (IAC). Together, both provide *timing* and *neutron impulse* response information necessary to be deconvolved out of the real data.

the light guide; and (3), the transit time through the photomultiplier tube and base, which has been measured by National Security Technologies (NSTec) [28]. A schematic of this is shown in Figure 32.

As mentioned, the transit time of a 2.45 MeV neutron through a 2.54 cm (1 inch) scintillator is 1.2 ns; thus, *the average is half that value*, since a neutron can interact on the front face or it can interact on the back face – therefore, it is taken to be 0.6 ns. The transit time of the light that is produced and travels through the light guide is merely the length of the light guide, l , divided by c/n , where c is the speed of light and n is the index of refraction for the light guide material. This is known to be 1.2 ns. This was

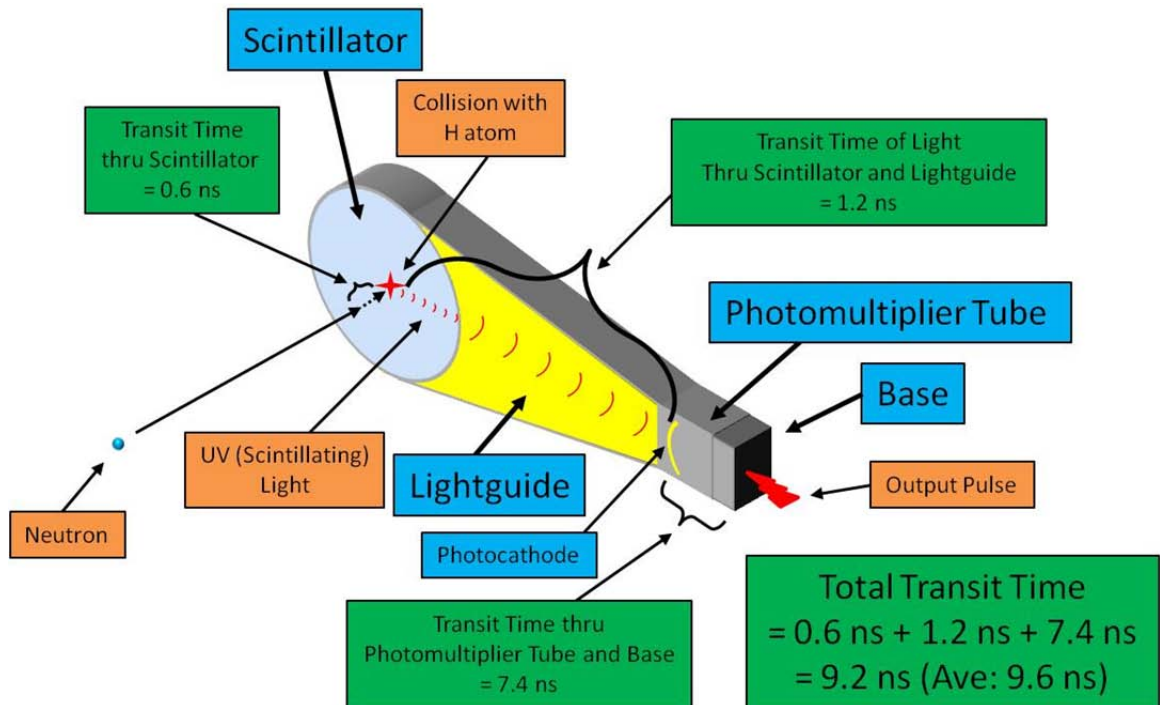


Figure 32. Schematic of the time delays that need to be taken into account (green boxes). The detector shown is a “single paddle” nTOF detector. A neutron (at left) penetrates the center of the scintillator and has a collision with a hydrogen atom. The time from the neutron entering the scintillator to when it interacts is its *transit time*, and was found above to be 0.6 ns. The time the UV (scintillating) light reaches the light guide (yellow), and travels the length of the light guide is 1.2 ns. Upon reaching the photocathode in the photomultiplier tube, the light is converted into an electronic signal, emerging from the base with a transit time of 7.4 ns, measured by National Security Technologies (NSTec) [28]. The sum of all transit times are 9.2 ns, but with fielding several nTOF detectors, it was considered that the average transit time to be 9.6 ns.

taken from the center of the scintillator as an average value. Finally, the transit time through the photomultiplier tube and base, measured by NSTec [28], is 7.4 ns. The sum of all these delays is 9.2 ns. This was done for every nTOF detector fielded, with an average value to be 9.6 ns to be the total delay from when radiation impinges upon the face of the scintillator to the electronic signal coming out of the base of the photomultiplier tube.

Once all the time delays have been taken into account, it is then necessary to correct Figure 31 in terms *where the actual time/neutron response starts*. This is

because when the time responses were found experimentally at Idaho State, there was no fiducial present to indicate the time radiation was impinging upon the detector. Therefore, a value of 5% of the amplitude in Figure 31 was taken to be the start of the output pulse of the detector, and from that point, 9.6 ns earlier in time was taken to be the point at which radiation impinged upon the detector. This is shown in Figure 33.

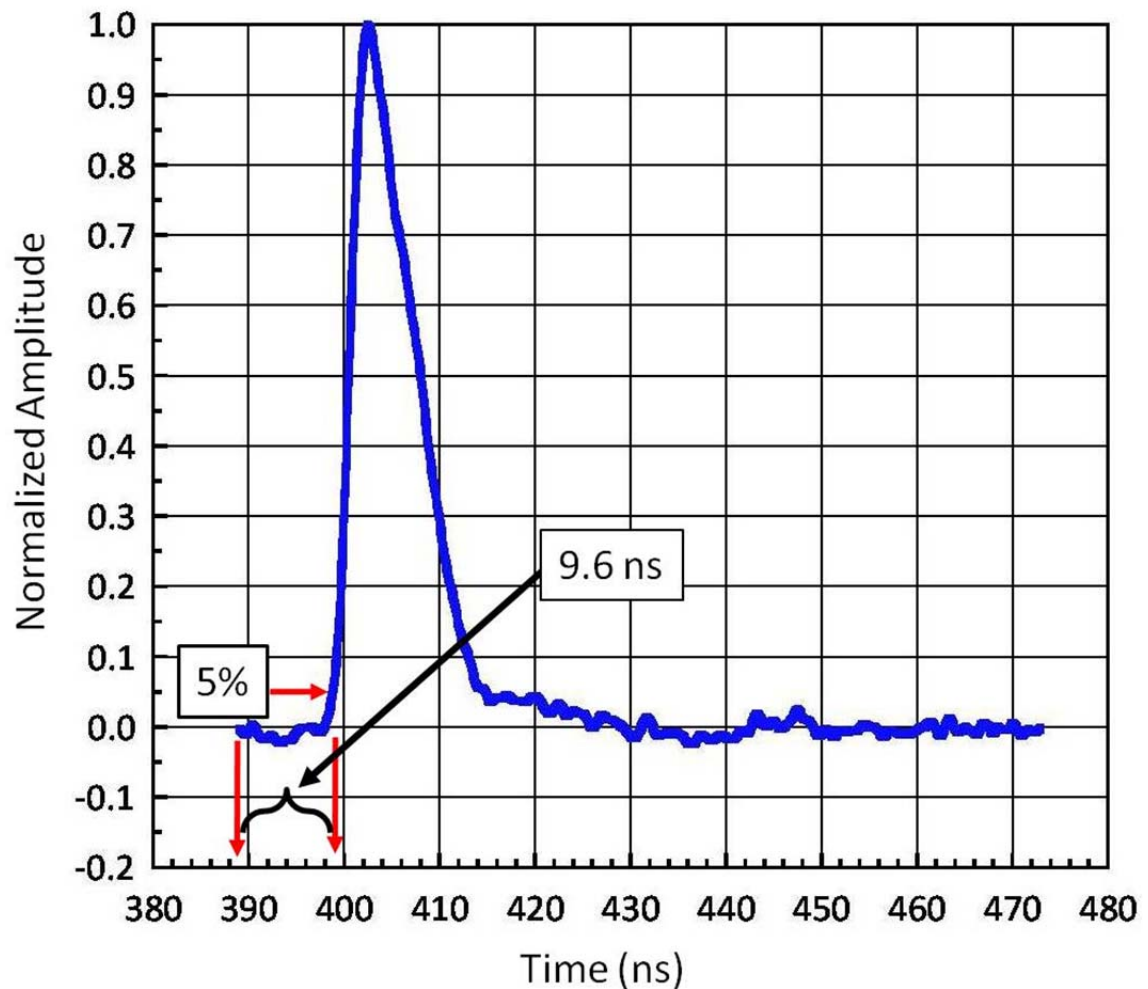


Figure 33. The Neutron Impulse/Time Response corrected for the time when radiation first impinges upon the detector. From the point of 5% of shot breakout, 9.6 ns earlier in time indicates the time in which radiation first impinges upon the detector (In this case, radiation first strikes the detector at 389.11 ns). 9.6 ns is the time it takes for the signal to traverse the entire detector – scintillator, light guide, photomultiplier tube and base – before an electronic signal (the pulse shown above) is produced.

CHAPTER 9

DECONVOLVING THE NEUTRON AND TIMING INSTRUMENT RESPONSE OUT OF THE REAL DATA

The neutron and timing instrument response (the convolution of both timing and neutron impulse information) in Figure 33 was now placed in “wrap-around order” (see Figure 27) and deconvolved out of the empirical data. The result is shown in Figure 34. Note that the neutron peak is at 373.53 ns (see arrow), and that the neutron peak from the empirical data (Figure 26) is at 383.13 shakes. The deconvolution has shifted the waveform *earlier in time*, because the time response information has been removed from the data. The neutron peak has been shifted back in time by 9.6 ns. This is a check that causality has not been violated. Neutrons *must arrive earlier* than the signal that is produced [29].

As a check to see if the deconvolution is correct, the waveform in Figure 34 was convolved with Figure 33 and compared with the empirical data. The results are shown in Figure 35 as an area normalized plot. The blue waveform is the empirical data from z1217, and the red waveform is the convolved signal. As can be seen, the red falls neatly on top of the blue with extremely small variations, indicating a very good fit.

SUBTRACTING THE CONTRIBUTION DUE TO NEUTRON SCATTERING

Once the time and neutron impulse response have been deconvolved out of the data, the contribution due to scattering can then be subtracted out. This is accomplished by running an “Ideal Case” case of a 2.54 cm (1 inch) scintillator 809 cm from a 4 keV DD fusion source (shown in Table II), with no material between the

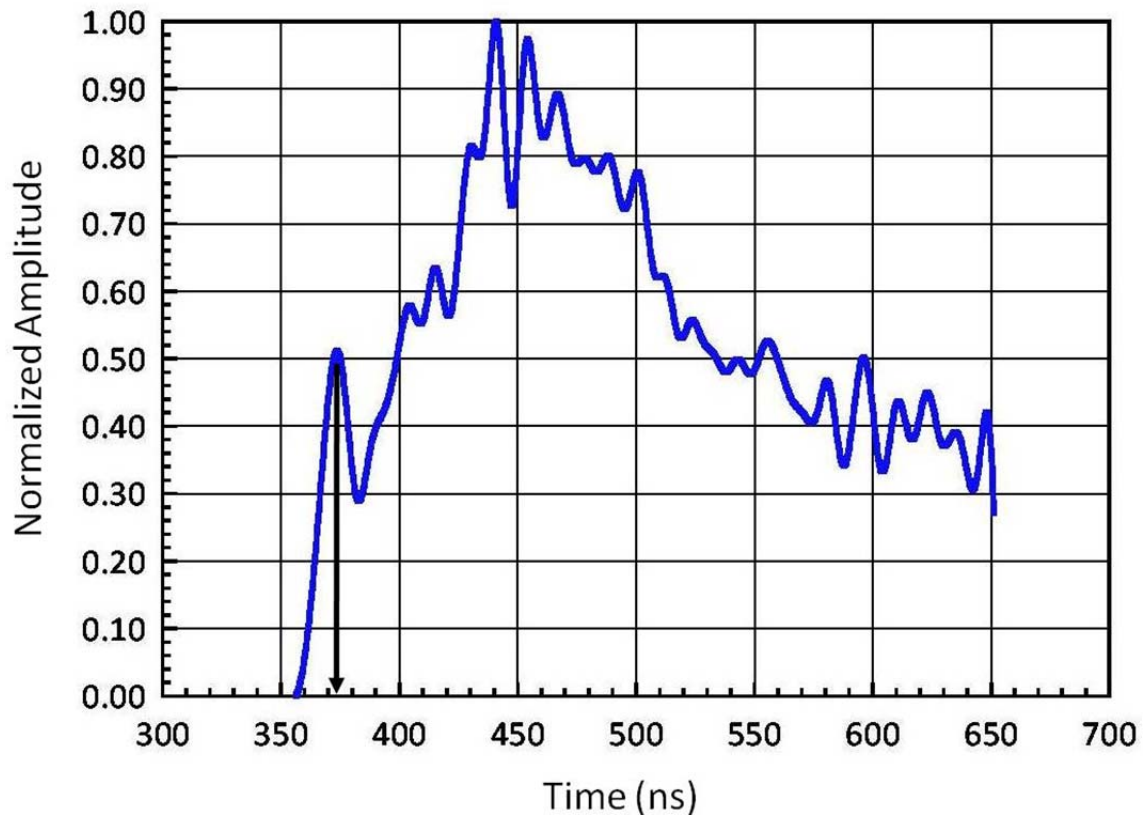


Figure 34. The empirical data from shot z1217 with the neutron impulse and timing information (Figure 31) deconvolved out of it. Note that the neutron peak is at 373.53 ns (see arrow) vs the neutron peak in the empirical data (Figure 26) at 383.13 ns. The deconvolution has shifted the waveform earlier in time by 9.6 ns – indicating that the time response information has been removed from the data. The delay above *must be at least* 9.6 ns, in order that causality not be violated – neutrons *must arrive earlier* than the signal that is produced.

source and scintillator, and comparing a case run with all the geometry and materials in the problem with the 2.54 cm (1 inch) scintillator at the same location (shown in blue in Figure 15). A plot of the “Ideal Case” being subtracted out from the “Full Scale” geometry leaving the contribution to scattering is shown in Figure 36. It is interesting to note that there is a small hump (green) due to scattering early in time, indicating that some shallow angle scattering is occurring, contributing to the signal. Not much can be said for the tail, as this is dominated by the huge, second scattering peak produced from

lack of a neutron collimator near the source. Looking at the full width at half maxima in Table III – subtracting the FWHM of the “Ideal Case” from the FWHM of the “Full Scale” geometry in Figure 36 – one sees that the broadening due to scattering is 3.857 ns.

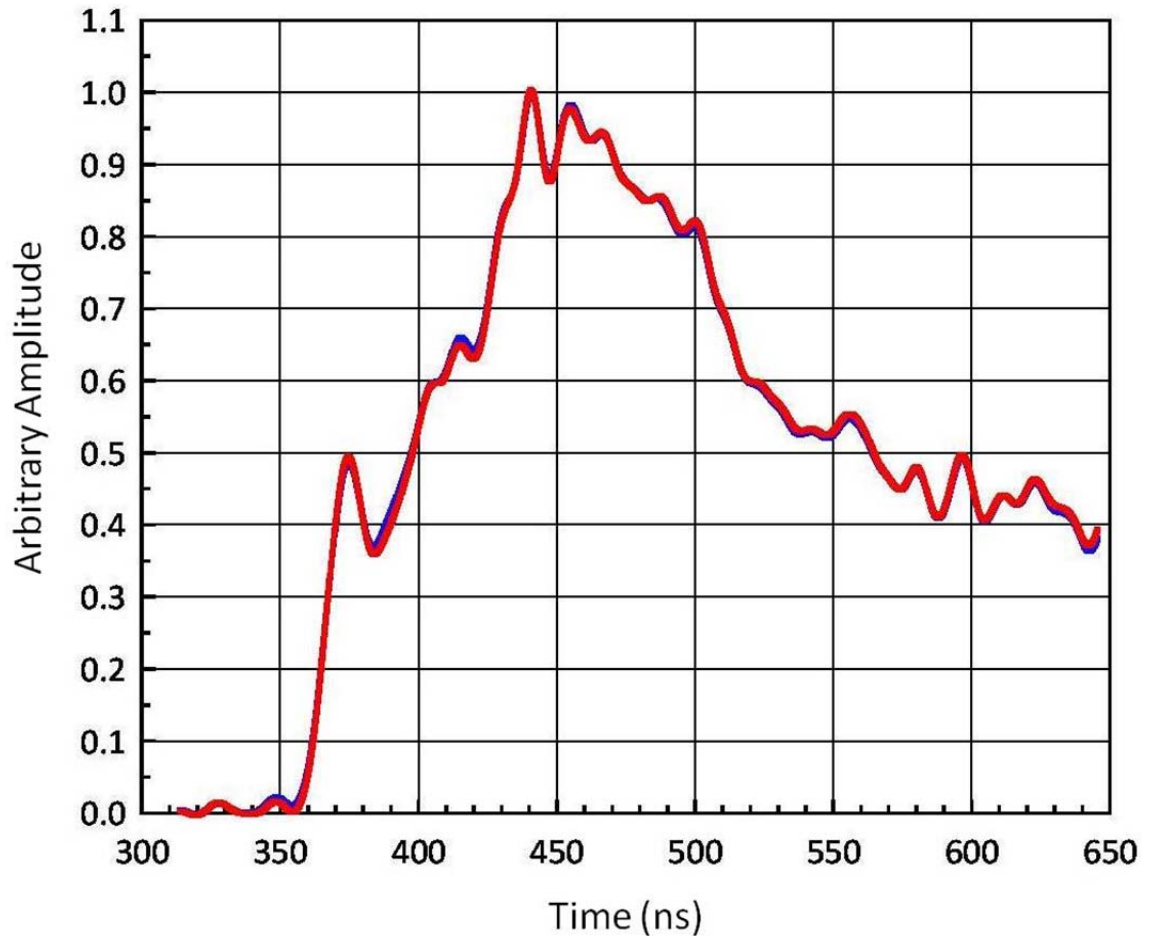


Figure 35. Area Normalized plot of the empirical data from z1217 (blue) compared with Figure 33 and Figure 34 being convolved together (red) as a “check” of the deconvolution. As can be seen, the red falls neatly on top of the blue with extremely small variations, indicating a very good fit.

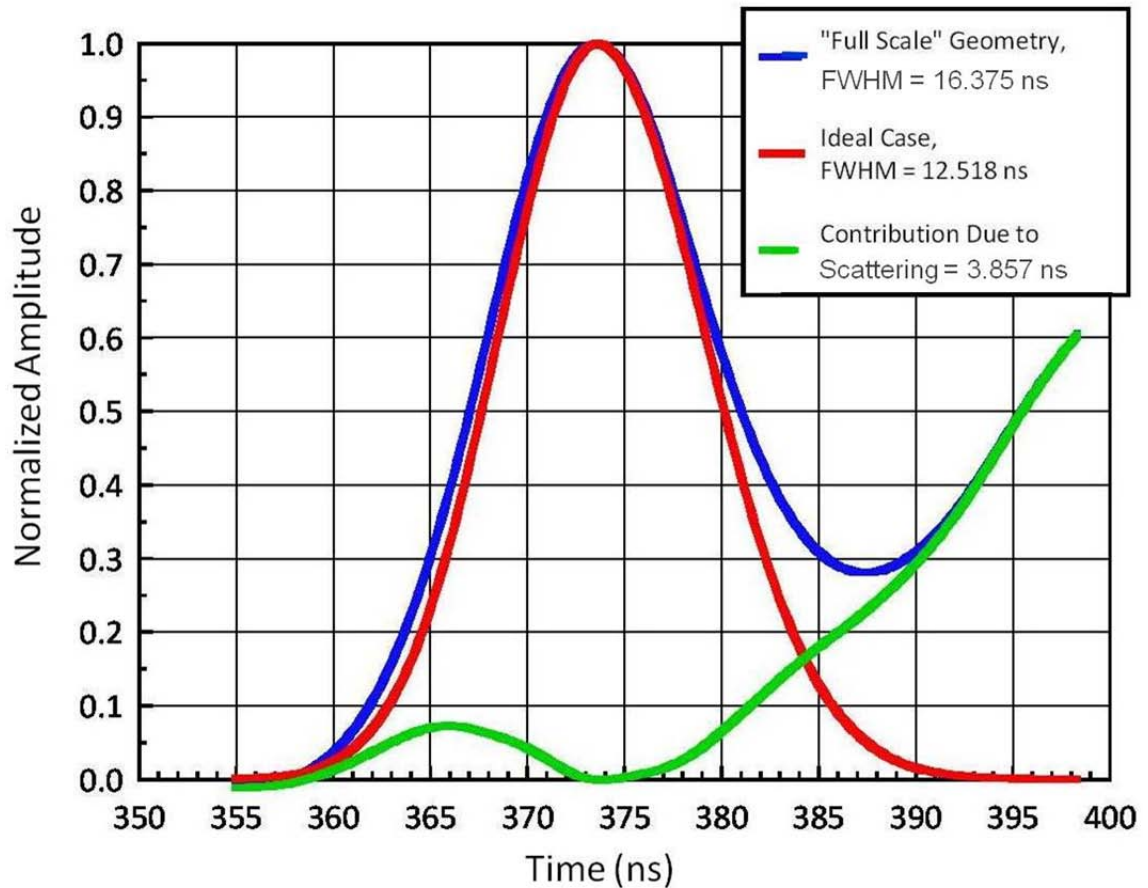


Figure 36. The “Ideal Case” (red) – i.e., a 2.54 cm (1 inch) scintillator placed 809 cm away from a 4 keV DD Fusion Source is subtracted out from the “Full Scale” Geometry (i.e., the scintillator in the same location but now with all the geometry of the problem added; blue). The result is the contribution due to scattering (green). Of interest is the small hump due to scattering early in time, indicating that indeed, there is some shallow-angle scattering contributing to the signal. Not much can be said for the tail, as this is dominated by the huge, second scattering peak produced from lack of a neutron collimator near the source. Subtracting the FWHM of the Ideal Case from the Full Scale Geometry leaves 3.857 ns, which is the amount of broadening that scattering contributes.

Once the contribution due to neutron scattering has been found (green in Figure 36), it could now be subtracted from the waveform in Figure 34 – the empirical data from z1217 with the time response and neutron impulse response deconvolved out of it. This is shown in Figure 37. The data is now ready to be transformed from the time domain (dN/dt) to the energy domain (dN/dE) to infer a neutron spectrum.

Table III.

Broadening due to Scattering at Detector Location “D” with no Collimator.

<u>Waveform</u>	<u>FWHM (ns)</u>
“Full Scale” Geometry (Bottom nTOF)	16.375
“Ideal Case”	12.518
Broadening Due to Scattering:	$16.375 - 12.518 = \underline{3.857 \text{ ns}}$

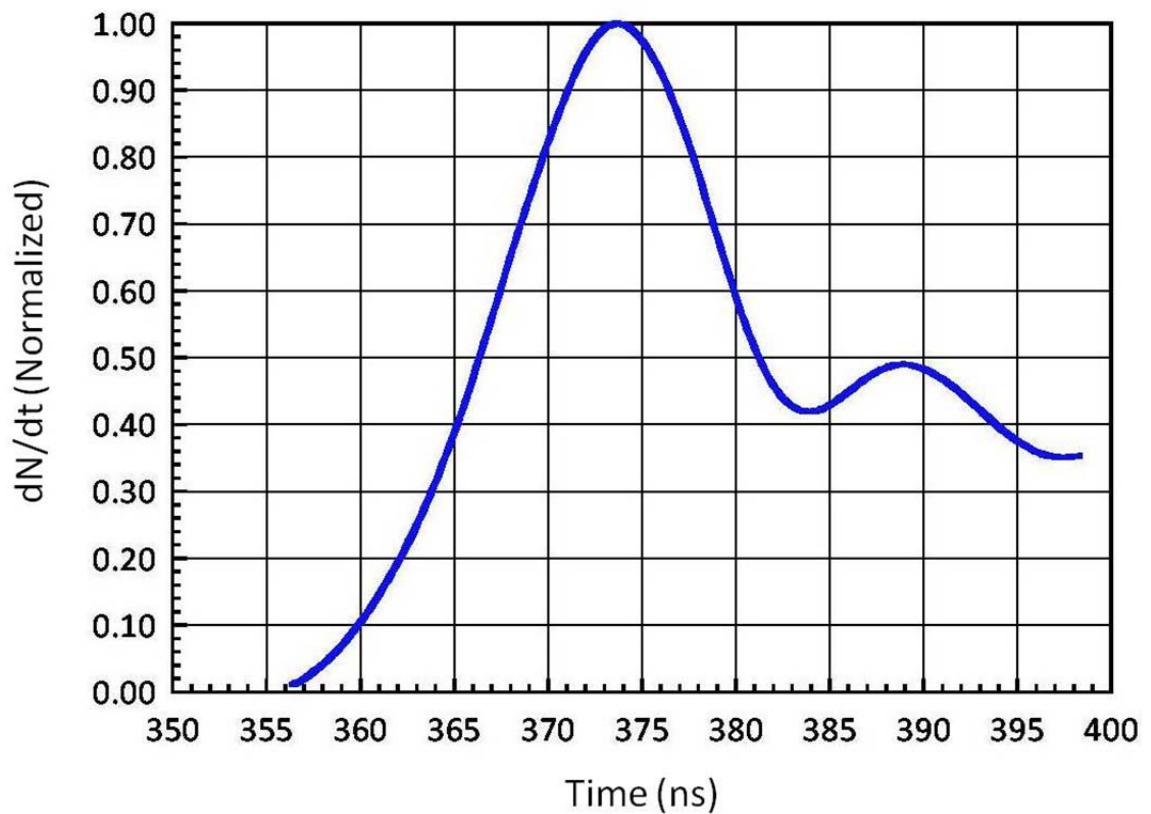


Figure 37. The empirical data from z1217 with the time response and neutron impulse response deconvolved out of it, and now with the contribution due to scattering (green in Figure 36) subtracted out of it. The data is now ready to be transformed from the time domain (dN/dt) to the energy domain (dN/dE) in order to produce a neutron spectrum.

CHAPTER 10

MAKING THE TRANSFORMATION FROM (dN/dt) to (dN/dE)

In the real world, the signal produced by an nTOF detector is in *Voltage vs Time*, due to the fact that the small amount of light output produced in the scintillator is converted to an electrical signal in the photomultiplier tube. The amplitude of this waveform is directly related to the number of incident neutrons that interacted in the scintillator. Thus, one could also refer to an nTOF signal as dN/dt , or number of neutrons interacting in the scintillator vs time. This is a known quantity. Unfortunately, what is not known is dN/dE , which is related to dN/dt by:

$$\frac{dN}{dt} = \frac{dN}{dE} * \frac{dE}{dt} \quad (19)$$

Solving for dN/dE :

$$\frac{dN}{dE} = \frac{\frac{dN}{dt}}{\frac{dE}{dt}} \quad (20)$$

From equation (9) above:

$$E = \frac{1}{2} m v^2 \quad (21)$$

Putting v in terms of t:

$$E = \frac{1}{2} m_0 \frac{c^2}{c^2} \left(\frac{l}{t}\right)^2 \quad (22)$$

let $m = m_0 c^2 = 939.5054 \text{ MeV}$, and taking the derivative of (22) with respect to t:

$$\frac{dE}{dt} = -\frac{m}{c^2} \frac{l^2}{t^3} \quad (23)$$

Taking the absolute value of dE/dt :

$$\left| \frac{dE}{dt} \right| = +\frac{m}{c^2} \frac{l^2}{t^3} \quad (24)$$

Solving for t in equation (22):

$$t = \sqrt{\frac{ml^2}{2c^2E}} \quad (25)$$

And t^3 becomes:

$$t^3 = \left[\frac{ml^2}{2c^2E} \right]^{3/2} \quad (26)$$

Substituting the value of dE/dt in (24) into (20) becomes:

$$\frac{dN}{dE} = \frac{dN}{dt} * \frac{c^2 t^3}{ml^2} \quad (27)$$

Substituting the value of t^3 in (26) into (27):

$$\frac{dN}{dE} = \frac{dN}{dt} * \frac{c^2}{ml^2} \left(\frac{ml^2}{2c^2E} \right)^{3/2} \quad (28)$$

Simplifying:

$$\frac{dN}{dE} = \frac{m^{1/2} l}{2c\sqrt{2} E^{3/2}} * \frac{dN}{dt} \quad (29)$$

Defining constants:

$$K(l)_E = \frac{m^{1/2} l}{2c\sqrt{2}}, \text{ and } K(l)_t = \frac{c^2}{ml^2} \text{ such that:} \quad (30)$$

$$\frac{dN}{dE} = K(l)_E * \frac{dN}{dt} * E^{-3/2} \quad (31)$$

and:

$$\frac{dN}{dE} = K(l)_t * \frac{dN}{dt} * t^3 \quad (32)$$

Equation (31) is used to solve for dN/dE and equation (22) to solve for E . The values of dN/dt in (31) are those of the ordinate of Figure 37 and the values of t are those of the abscissa of Figure 37. The units of equation (31) must be $\#/\text{MeV}$, and those of equation (22) are MeV . A plot of the transformation from dN/dt from Figure 37 to dN/dE is shown in Figure 38. It is the neutron spectrum for shot z1217 at detector location “D” in Figure 1. The time response (Figure 13), and the neutron impulse response (Figure 29), convolved together (Figure 31) to include both *timing information and neutron impulse information* (Figure 31) was deconvolved out of the data (Figure 34), and the contribution to scattering was subtracted out (Figure 36, green), leaving the true dN/dt signal (Figure 37). The transformation to dN/dE – the neutron spectrum is shown in Figure 38. It should be noted that the energy bins along the ordinate *are not equal* after the transformation is made, with larger bins at high energies, but the data can be interpolated with the bin width of the smallest energy bin at the extreme end of the data.

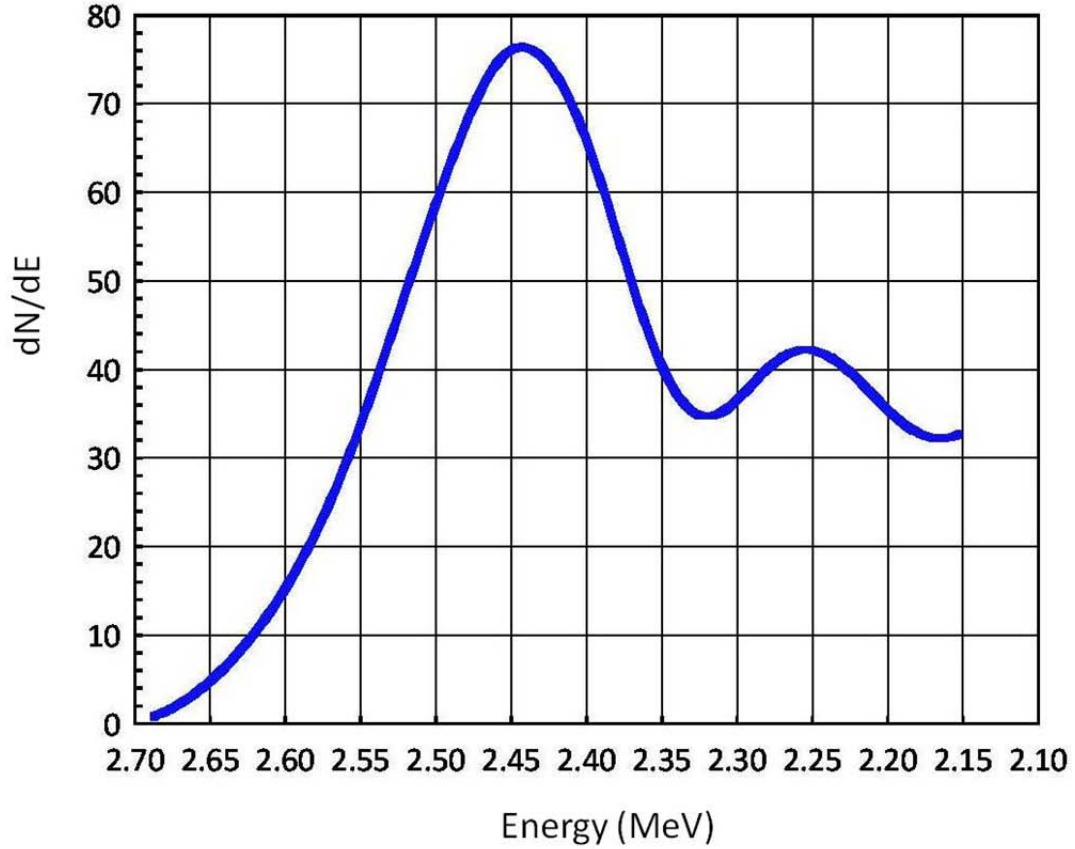


Figure 38. The Transformation from dN/dt (Figure 34) to dN/dE , the neutron spectrum for shot z1217 at detector location “D” in Figure 1. The time response and neutron impulse response have been deconvolved out of the data, and the contribution due to scattering has been subtracted out. The humped “tail” seen at ~ 2.25 MeV is not to be believed because of the enormous scattering tail (green in Figure 36).

According to the equation:

$$\int_{E_{min}}^{E_{max}} \frac{dN}{dE} dE = \int_{t_{min}}^{t_{max}} \frac{dN}{dt} dt \quad (33)$$

the integral of dN/dE in Figure 38 *must equal* the integral of dN/dt in Figure 37. Before integrating dN/dE (Figure 38), the smallest bin width found at the end of the data must be used to interpolate the data, because all the bin widths need to be the same before integrating. Table IV below shows that both integrals are the same.

Table IV.

Integrals of dN/dt (Figure 37) and dN/dE (Figure 38)

<u>Waveform</u>	<u>Integral</u>
dN/dt (Figure 37)	1.84385
dN/dE (Figure 38)	1.84386

For the nTOF detector located at position “C” in Figure 1, the top nTOF in the basement “pig”, the same analysis was performed, and the contribution due to scattering is shown in Figure 39 (green). It was found by subtracting the “Ideal Case” full width at half maxima from the “Full Scale” geometry full width at half maxima. The broadening due to scattering at detector location “C” in Figure 1 with no collimator is 3.89 ns.

The contribution to scattering in the top nTOF was subtracted from the data after having the time response and neutron impulse response deconvolved out of it, and the transformation from dN/dt to dN/dE was made. It is shown in Figure 40, plotted alongside the spectrum found at the bottom nTOF location (Figure 38). The Bottom nTOF spectrum’s peak is located at 2.46 MeV, and the top nTOF spectrum’s peak is at 2.44 MeV. The “tails” are not to be believed, since scattering was such an issue.

Later on in Z’s history the Ultra-High Molecular Weight (UHMW) TIVAR collimator (Figure 19) was added to neutron producing shots to “clean up” the neutron signals.

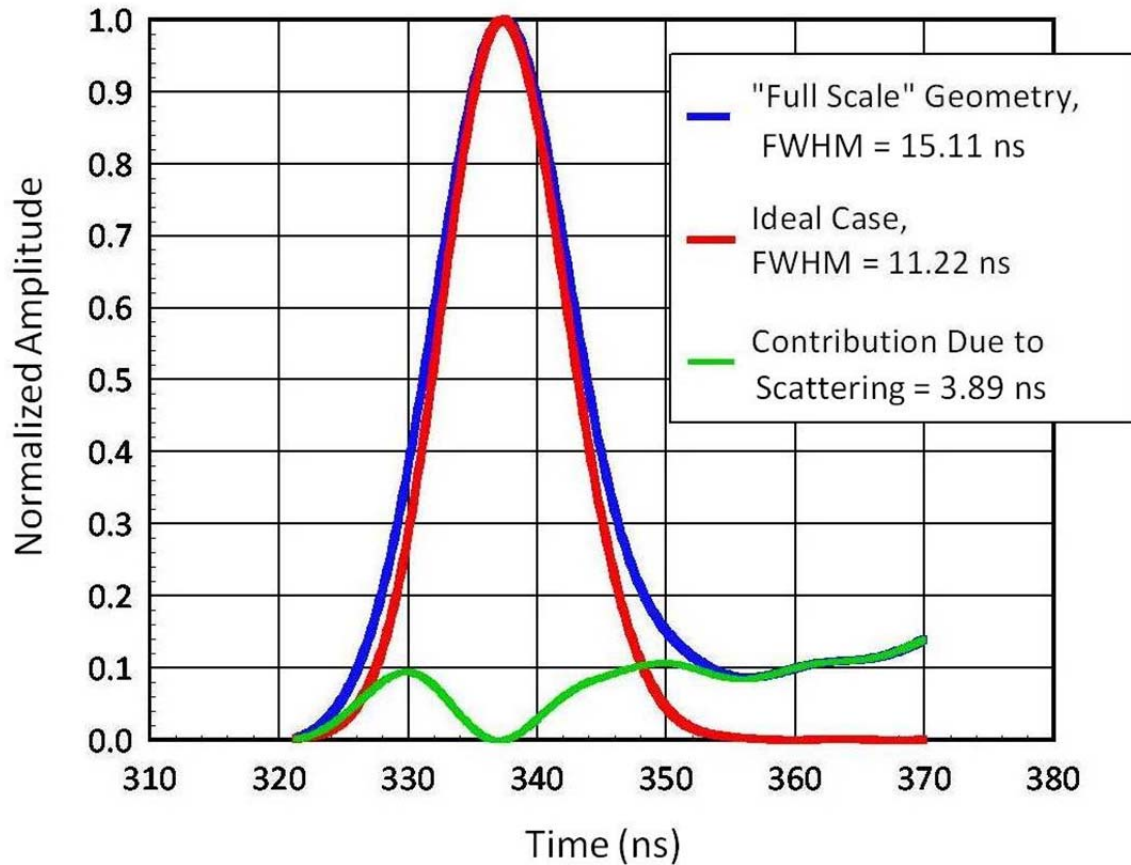


Figure 39. The "Ideal Case" (red) – i.e., a 2.54 cm (1 inch) scintillator placed 730 cm (location "C" in Figure 1) away from a 4 keV DD Fusion Source is subtracted out from the "Full Scale" Geometry (blue). The result is the contribution due to scattering (green). Subtracting the FWHM of the "Ideal Case" from the FWHM of the "Full Scale" Geometry leaves 3.89 ns, which is the amount of broadening that scattering contributes.

And as shown in Figures 22 and 24, it greatly reduced the second scattering "tail" for detector location "D" (Figure 1) and virtually eliminated the second scattering tail at detector location "C" (Figure 1).

On shot z1549 both detector signals from the basement "pig" were analyzed. Once the time response and neutron impulse response was deconvolved out of the data, the contribution to scattering was determined for detector location "D" (Figure 1) and shown in Figure 41. The "Full Scale" geometry (blue) was run with the TIVAR 1000

collimator in place in the model, and it is compared to an “Ideal Case” (red) in Figure 41. The broadening due to scattering (green) is the “Ideal Case” subtracted from the “Full Scale” geometry, and is 2.849 ns.

Table V.

Broadening due to Scattering at Detector Location “C” with no Collimator.

<u>Waveform</u>	<u>FWHM (ns)</u>
“Full Scale” Geometry (Bottom nTOF)	15.11
“Ideal Case”	11.220
Broadening Due to Scattering:	$15.11 - 11.220 = \underline{3.89 \text{ ns}}$

This is less than the value of 3.857 ns shown in Figure 36 and Table III, indicating that the collimator is reducing some shallow-angle scattering into the detector. Some shallow-angle scattering is still contributing to the signal – this is due to the fact that the “bore” on the collimator is quite large, 7.62 cm (3 inch) diameter, and as shown in Figure 20, the “collimator cone” spreads out to a 116 cm (45.7 in) diameter at the basement floor. The collimator also reduces the second scattering tail drastically in Figure 41 compared to Figure 36.

Analysis of the top nTOF signal when the collimator was added (position “C” in Figure 1) was performed and is shown in Figure 42. The “Full Scale” geometry (blue) was run with the TIVAR 1000 collimator in place, and it is compared to the “Ideal Case”

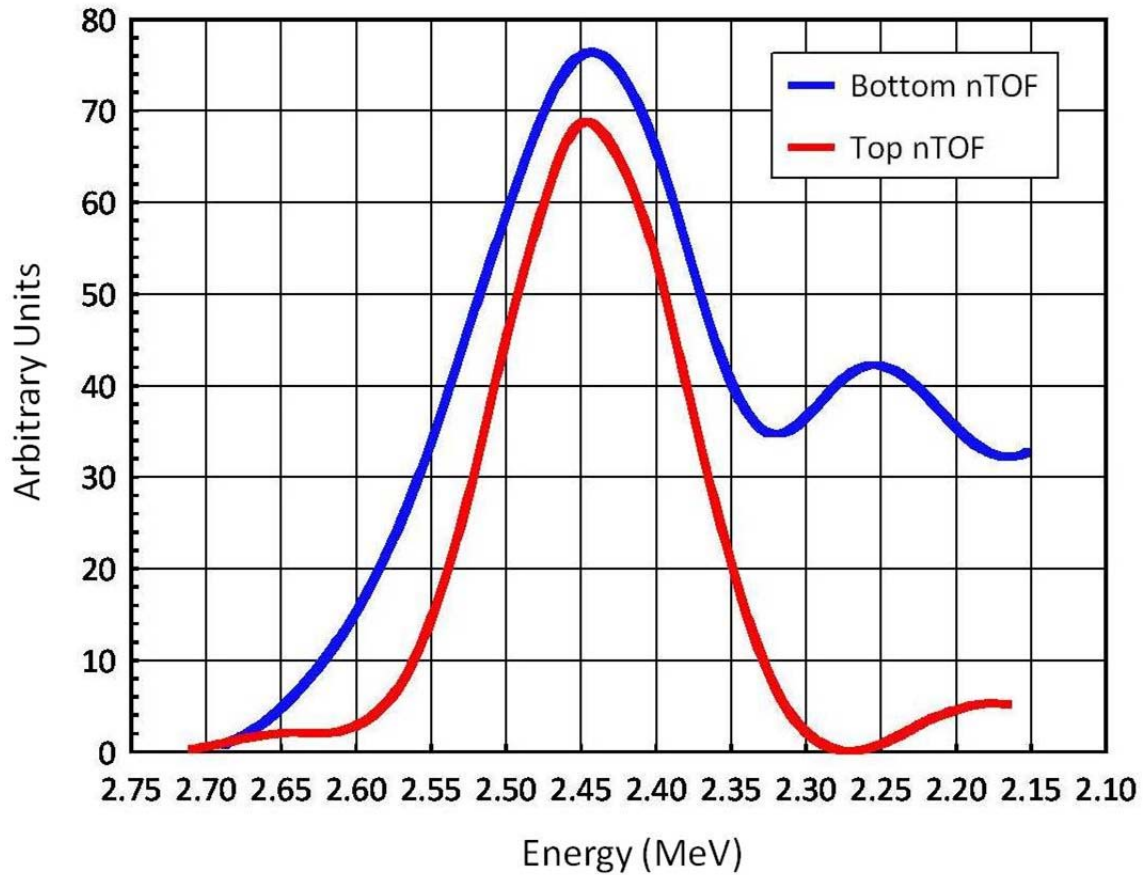


Figure 40. Energy Spectra for both the Top and Bottom nTOF detectors at locations “C” and “D” in Figure 1 from shot z1217. Although not identical, they are similar in shape. The Bottom nTOF spectrum’s peak is at 2.46 MeV, while the Top nTOF spectrum’s peak is at 2.44 MeV. Note that Energy along the abscissa decreases as one moves to the right. The “tails” are not to be believed, since scattering was such an issue.

(red). The broadening to scattering (green) is the “Ideal Case” subtracted from the “Full Scale” geometry, and is 3.176 ns, shown in Table VII. This is less than 3.89 ns shown in Figure 39 and Table V, indicating that again, the collimator is reducing shallow angle scattering into the detector. And, as in the case of Figure 41, the collimator does effectively reduce the second scattering tail seen in Figure 39.

Table VIII shows the contributions due to scattering for both detectors, with and without the collimator. The addition of the collimator reduced the broadening due to scattering for detector location “D” in Figure 1 (the Bottom nTOF) by 26.1 %. The

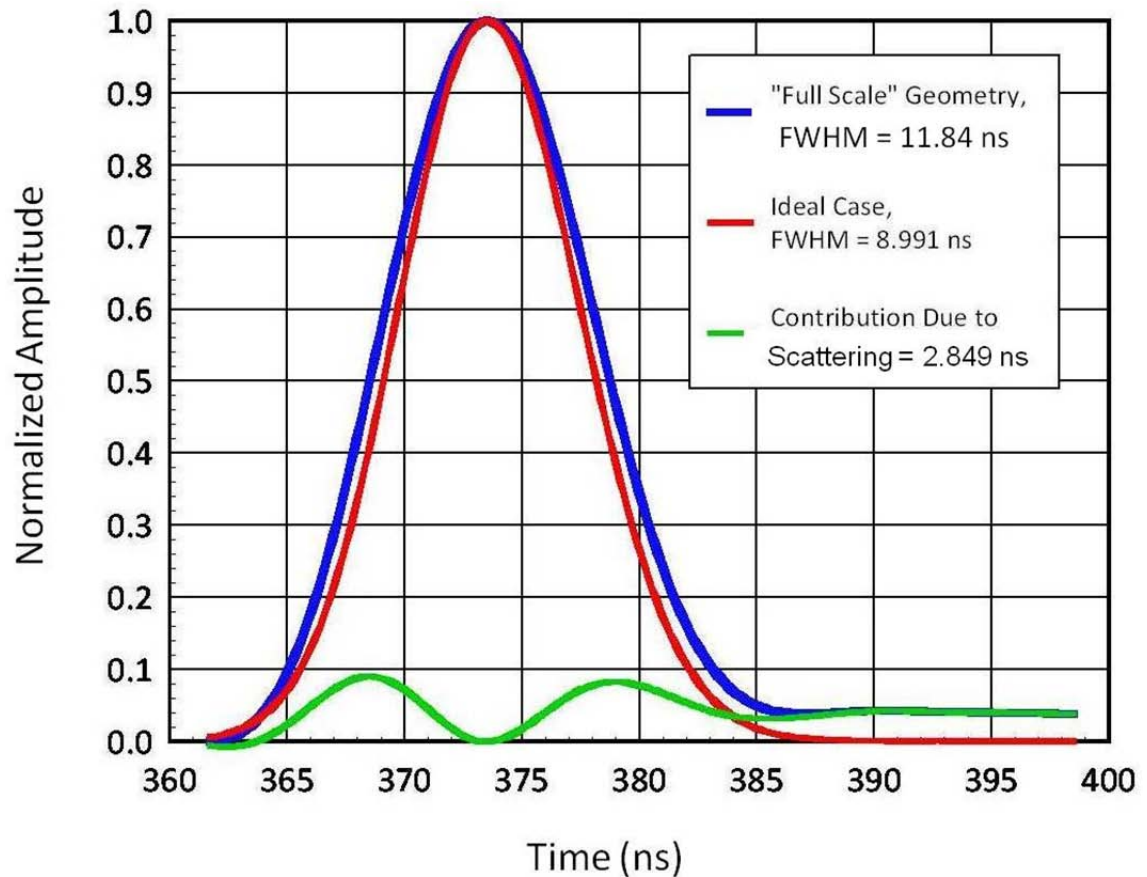


Figure 41. The “Ideal Case” (red) – i.e., a 2.54 cm (1 inch) scintillator placed 809 cm away from a 2 keV DD Fusion Source is subtracted out from the “Full Scale” Geometry (including the TIVAR collimator; blue). The result is the contribution due to scattering (green). What clearly can be seen is the reduction of the scattering tail in Figure 38 compared to Figure 33 – this is a direct result of the addition of the Tivar collimator. Subtracting the FWHM of the “Ideal Case” from the FWHM of the “Full Scale” Geometry leaves 2.849 ns, which is the amount of broadening that scattering contributes at detector location “D” in Figure 1.

addition of the collimator reduced the broadening due to scattering for detector location “C” in Figure 1 (the Top nTOF) by 18.4 %. Reduction of shallow angle scattering could be increased even further if the “bore” of the collimator were reduced in size

from 7.62 cm (3 inches) to a smaller diameter, but as shown in Figure 21, reducing the diameter would occlude the scintillators' view of the source, because the "pig" is tilted 3° from vertical.

Table VI.

Broadening due to Scattering at Detector Location "D" with a Collimator.

<u>Waveform</u>	<u>FWHM (ns)</u>
"Full Scale" Geometry (Bottom nTOF)	11.84
"Ideal Case"	8.991
Broadening due to Scattering:	$11.84 - 8.991 = \underline{2.849 \text{ ns}}$

The contribution to scattering in both the Bottom nTOF and the Top nTOF was subtracted from the data after having the time response and neutron impulse response deconvolved out of them, and the transformation from dN/dt to dN/dE was made. Both spectra are shown in Figure 43. The Bottom nTOF spectrum's peak is at 2.44 MeV, while the Top nTOF spectrum's peak is located at 2.45 MeV.

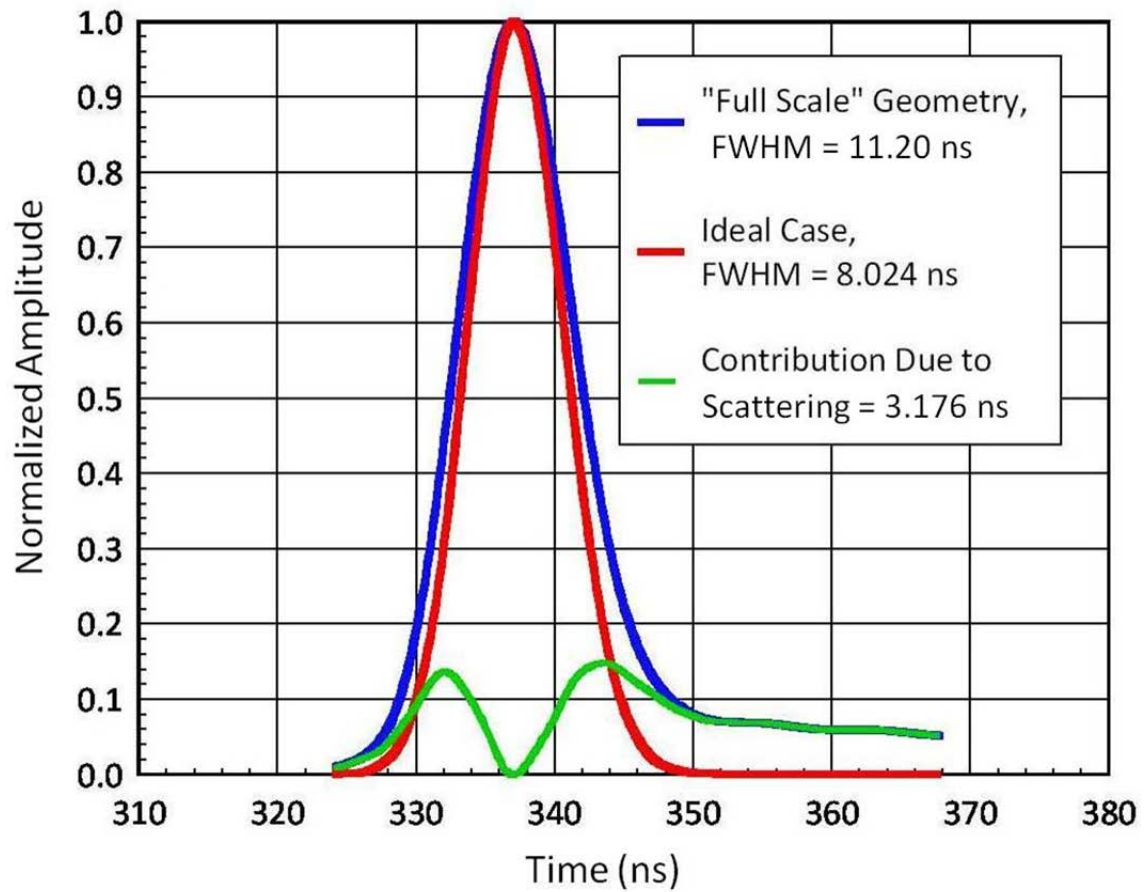


Figure 42. The "Ideal Case" (red) is subtracted from the "Full Scale" geometry (blue) to produce the contribution to scattering (green). This is the top nTOF located at position "C" in Figure 1, and was modeled at a temperature of 2 keV. The collimator does effectively reduce the second scattering peak shown in Figure 22. Subtracting the FWHM of the "Ideal Case" from the "Full Scale" Geometry leaves 3.176 ns, which is the amount of broadening that scattering contributes.

Table VII.

Broadening due to Scattering at Detector Location "C" with a Collimator

<u>Waveform</u>	<u>FWHM (ns)</u>
"Full Scale" Geometry (Top nTOF)	11.20
"Ideal Case"	8.024
Broadening due to Scattering:	$11.2 - 8.024 = \underline{3.176 \text{ ns}}$

Table VIII.

Broadening Due to Scattering for each Detector Location

	Without Collimator (ns)	With Collimator (ns)	% Reduction
Bottom nTOF, ("D")	3.857	2.849	26.1
Top nTOF, ("C")	3.89	3.176	18.4

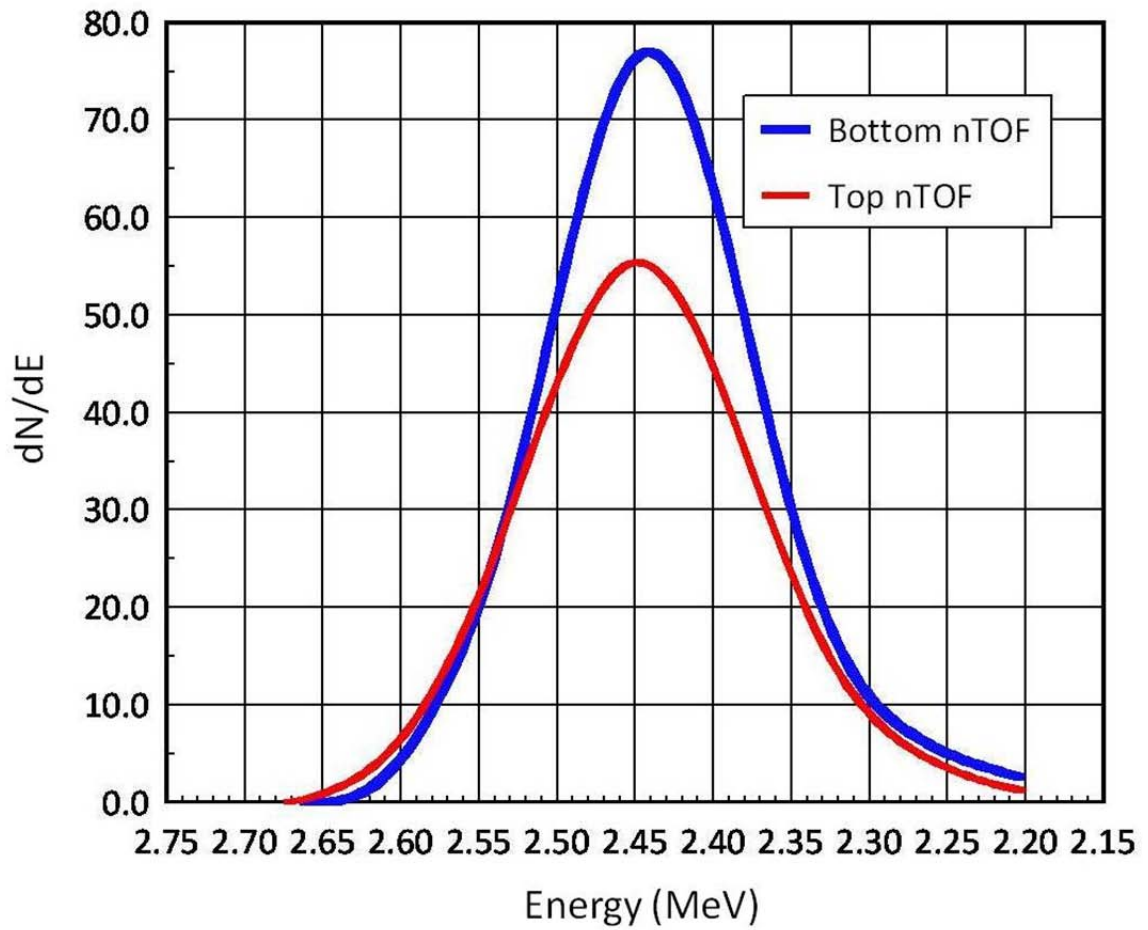


Figure 43. Energy Spectra for both the Top and Bottom nTOF detectors at locations "C" and "D" in Figure 1 from shot z1549. They are similar in shape. The Bottom nTOF spectrum's peak is located at 2.44 MeV, and the Top nTOF spectrum's peak is at 2.45 MeV. Note that Energy along the abscissa decreases as one moves to the right.

CHAPTER 11

IDENTIFYING SOURCES OF NEUTRON SCATTERING

An ideal neutron measurement would consist of detecting only those neutrons born at the source which arrive at the detector without interacting with any structural material in between. Experimentally, this can be difficult if not impossible, and depends on the facility, and the detector location. Collimation between the source and detector can greatly improve neutron signals, but may or may not be viable, depending on the facility. Therefore neutrons born at the source can and do undergo scattering off structural material and arrive at the detector, thereby “clouding” the pure signal, and making analysis of the plasma conditions at the source more difficult. One of the versatile aspects of this process described herein, however, is that the user -- upon suspecting certain materials to be contributors to neutron scattering -- can actually *test* if they are indeed a cause of concern. By changing cells’ importances to zero in the input deck (so that neutrons are killed when entering the cell) and changing the material that occupies the cells to a void, the user can then run the code, plot the light output and examine the detector response. The user can also identify whether photons or neutrons are responsible for any changes seen in the output, because the post-processing code can be easily modified to look at just the contribution of light output made from neutrons, photons, or both. This is illustrated in Figure 44. While the “mode” card in the input deck was turned on for both neutrons and photons, the source was a DD fusion neutron source and photons could only be produced by n,gamma capture reactions, therefore, virtually all the signal was produced from neutrons. As can

be seen, following the primary neutron signal, there are two “humps” caused by neutrons scattering into the detector later in time. The first “hump” is caused by neutrons scattering in through the sides of the pig, and the second “hump” is from neutrons scattering off the elevator floor.

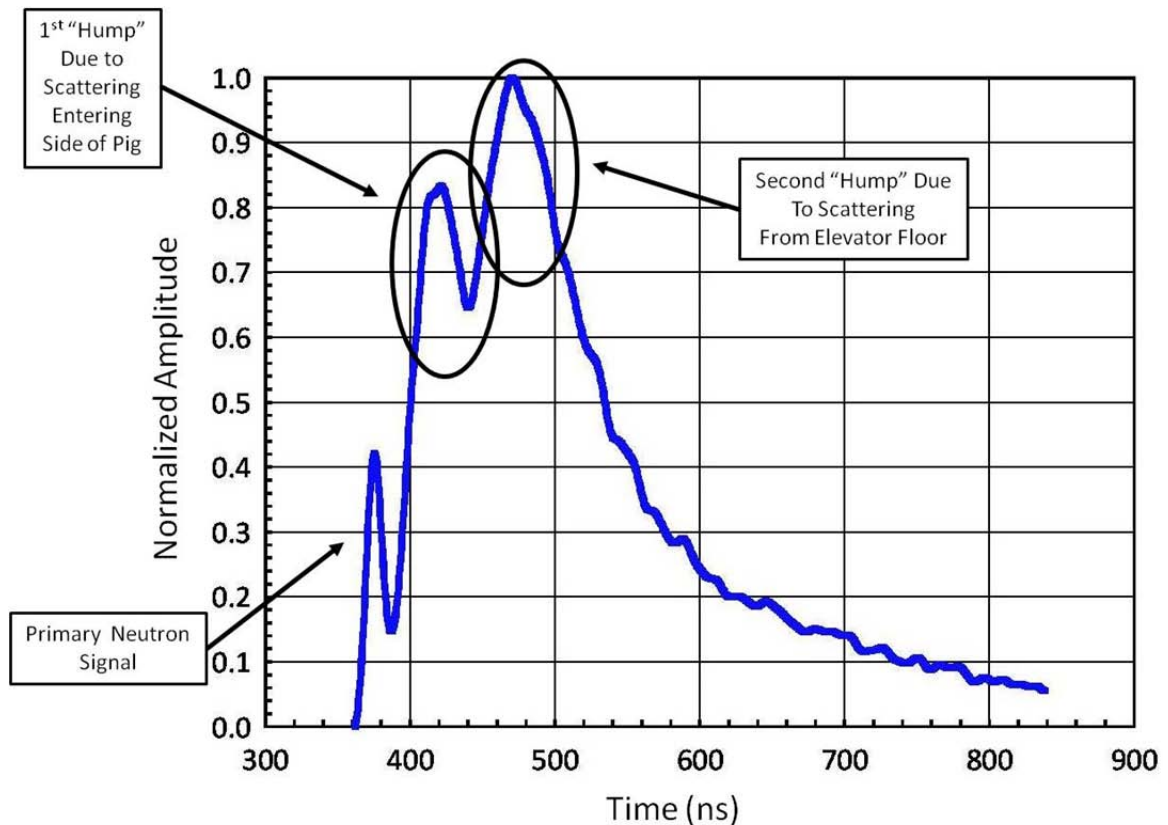


Figure 44. Neutron scattering after the primary pulse for detector location “D” in Figure 1. As can be seen, the first “hump” is from neutrons scattering through the side of the pig, and the second “hump” is caused from neutrons scattering off the elevator floor and arriving at the detector later in time.

The input deck was then modified by changing all the neutron importances for all the cells comprising the elevator floor to zero, and changing the cells of the elevator from steel to a void. This causes all neutrons that interact with the elevator to be “killed” (i.e., removed from the problem). The result is shown in Figure 45. Note the

second “hump” which was at ~ 470 ns is now gone, confirming that it is indeed due to neutrons scattering off the elevator floor. The first “hump” is still there, indicating that neutrons are still scattering in through the sides of the pig.

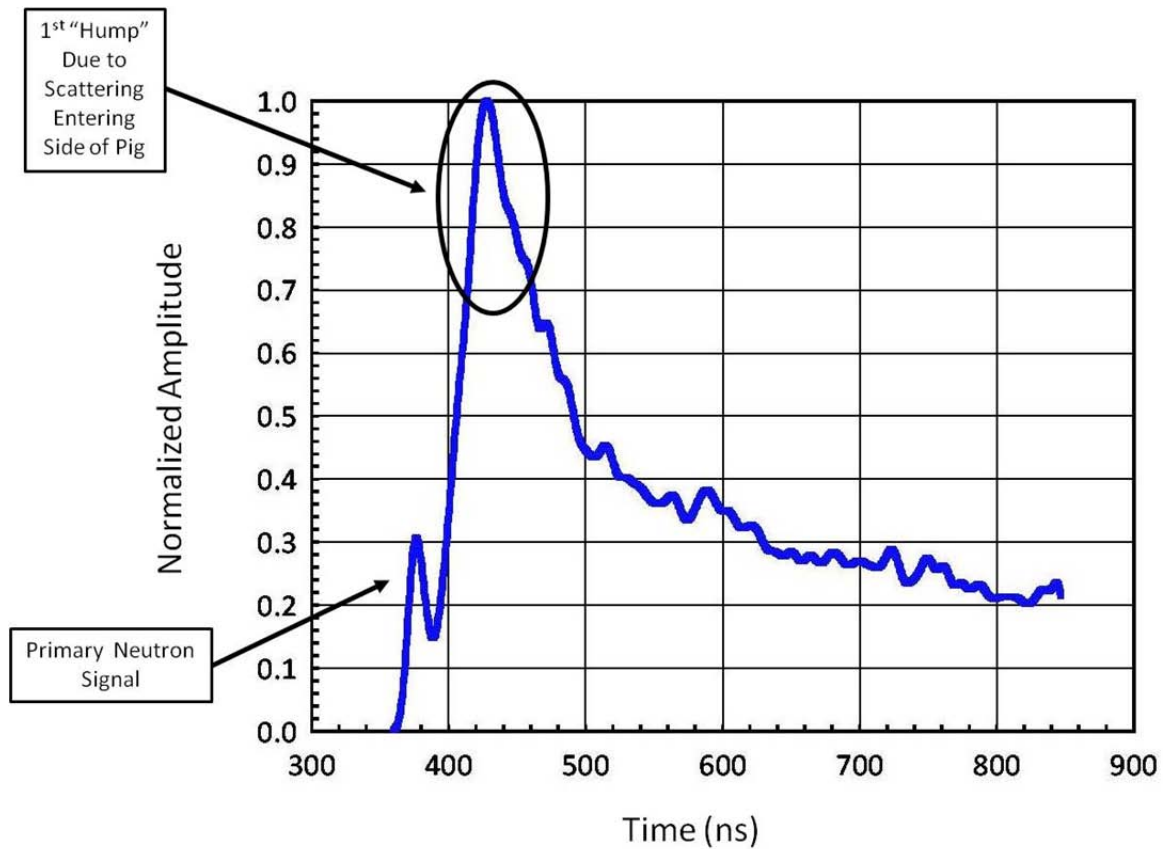


Figure 45. The elevator was made into a “kill” zone – i.e., any neutrons interacting with it were removed from the problem. The second “hump” seen in Figure 44 at ~ 470 ns is now gone, indicating that the elevator was indeed a cause of the second “hump”. The first “hump” is still there, indicating that neutrons are still scattering in through the sides of the pig.

The input deck was again modified by changing all the cell importances that comprised the sides of the pig to zero and changing their material from steel to a void (this is in addition to the elevator as shown in Figure 45). The result is shown in Figure 46. Note the first “hump” which appeared at ~ 430 ns is now gone, indicating that

neutrons were indeed scattering in through the sides of the pig. All that is left is the primary neutron signal.

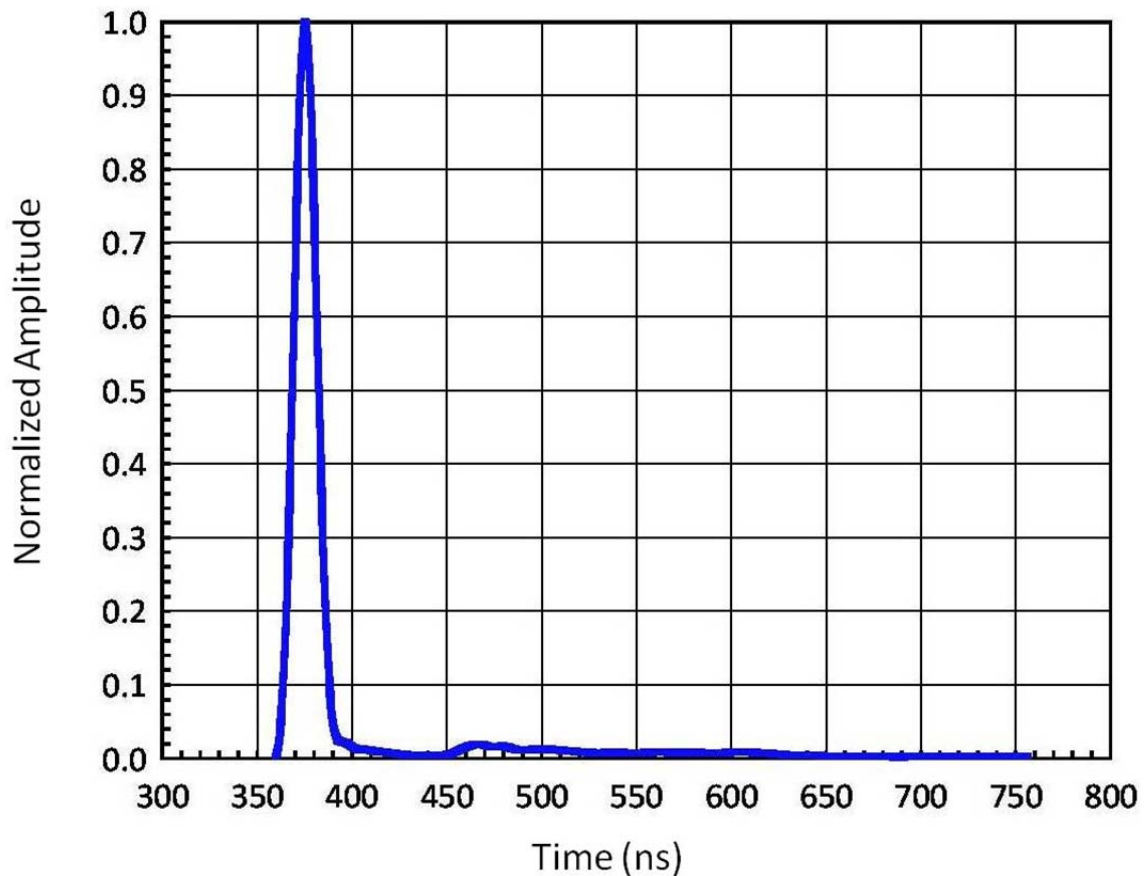


Figure 46. For the nTOF detector located at position “D” in Figure 1, both the elevator and the sides of the pig have been made into “kill” zones, thereby removing neutrons that interact with them, indicating that both the elevator and the sides of the pig were the contributors to scattering peaks later in time. All that is left above is the primary neutron peak.

In this way, this technique can be very useful in identifying sources of neutron scattering, and mitigating them if possible (by removing hardware that is a source of scattering near a detector, for example) or by adding neutron shielding in key areas identified by the code.

CHAPTER 12

CONCLUSIONS

A novel method of modeling the neutron time of flight (nTOF) detector response in current mode to inertial confinement fusion experiments has been presented. This process was first developed and then applied to the axial neutron time of flight detectors at the Z-Facility. First, the Z-Facility was modeled between the source and detector locations, which encompassed over 2400 cells and 900 surfaces with a user-modified version of MCNP, namely MCPN-PoliMi, which was developed by Enrico Padovani and Sara Pozzi in 2002. In order to obtain good statistics, many variance reduction techniques were utilized. MCNP-PoliMi simulates the detection of neutrons and photons in a plastic scintillator, and produces a collision data output table containing information of the incident particle (neutron or photon), target nucleus (hydrogen or carbon), energy deposited (MeV) and the time at which it occurred (shakes, [30]). A post-processing code was written to read this collision data output table. This converted the energy deposited by neutron and photon interactions in the plastic scintillator (i.e., nTOF detector) into light output, in units of MeVee (electron equivalent) vs time. A monoenergetic neutron case of 2.45 MeV was run at each detector location and convolved with the experimental time response found at the Idaho Accelerator Center (IAC) using their 15 MeV short pulse Linac with a 50 ps pulse width. This was done to provide both *timing and neutron impulse response information*. The resulting waveform was convolved with the simulated data and compared with the empirical results at each detector location, and was shown to be in good agreement.

For each detector, an experiment was performed, first without a neutron collimator below the source, and then with a neutron collimator fielded below the source. It was shown that the addition of the collimator resulted in greatly reducing the second scattering peak in both detector signals, but also reduced shallow-angle scattering in the bottom nTOF by 26.1%, and 18.4% in the top nTOF.

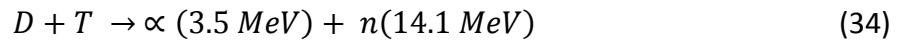
Then, as an additional step, the time response was deconvolved out of the empirical data. The contribution due to scattering was found by running a “Ideal Case” (i.e., nothing between the source and scintillator at each detector location); then a “Full Scale” geometry was run with all the structure added, and then subtracting one from the other. This scattering contribution was then subtracted from the empirical data. The resulting waveform was transformed from dN/dt to dN/dE , in order to produce neutron spectra for each detector location (Top and Bottom nTOF) and for each configuration (without collimator and with collimator).

The method developed here can be used to simulate the detector response of *any* nTOF detector, with any digitized resolution, at any facility. It has been found useful to address key issues such as scattering, which always plays a role in neutron detection when using nTOF detectors. It can be used to identify sources of scattering as well, and to improve neutron signals by modeling effective collimation. It is hoped by the author that this method will prove to be a useful tool in future modeling of experiments, where “clean” neutron signals will provide the greatest amount of information from whence they came.

FUTURE WORK

The techniques described herein have been shown to be extremely valuable in analyzing the data from dynamic holhraum experiments on Sandia National Laboratories' Z-machine. These techniques allowed the true neutron pulse shapes in the bottom nTOF detectors to be deconvolved from measured signals which in turn allows the determination of the neutron spectrum, the plasma ion temperature and the neutron yield. Since z-pinch fusion plasmas have historically been dominated by beam generated fusion reactions [31] which will result in there being an angular dependence in the neutron spectrum, it is important to apply this technique to the two (now three) side nTOF detectors, as well as the bottom two detectors, to better assess whether the neutrons observed are produced by a thermal plasma, beams, or a combination of the two.

These techniques could also be applied to other ICF facilities such as those at LLE [32] and LLNL [33]. This would include expanding the approach to include analyzing nTOF signals that measure the 14.1 MeV neutrons from the reaction:



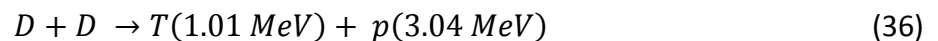
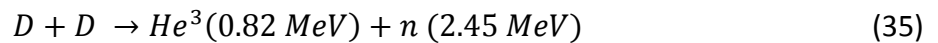
This D-T reaction will be the reaction of choice for all ignition experiments since this reaction has the highest reaction cross section of all fusion reactions and the peak of the cross section occurs at the lowest ion energy. In addition to helping to analyze nTOF signals as on Z, an example of another potential application would be to help in the transfer of nTOF detector calibrations between facilities. For example, nTOF detectors have been calibrated at LLE for use on NIF. Since the scattering environment at LLE is

not the same as at NIF, however, the transfer of the calibration is not straight forward. The use of the techniques described in this dissertation should be of great help in transferring these calibrations.

In addition to allowing the measurements of neutron yields, ion temperatures, and neutron spectra, nTOF detectors can be used to measure another extremely important parameter in inertial confinement fusion experiments: the ρR of the fuel (g/cm^2). Here ρ is the fuel density (g/cm^3) and R is the radius of fuel (cm), which is assumed to be spherical. For D-T fuel, the optimum value of ρR is $\sim 3 \text{g}/\text{cm}^2$ [34]. For low values of ρR , disassembly of the pellet becomes an issue, and for high values of ρR , fuel depletion becomes an issue. For fusion to be an energetically viable energy source most of the D-T fuel must be heated, not by the laser driver (for example), but by the fusion reactions themselves. Since most neutrons escape with little or no interactions, this self-heating of the fuel will rely on the energy deposition of the 3.5 MeV alpha particles in the fuel. It is envisioned that the laser will create a hot spot in the central core which ignites the fuel and that the resulting alphas will create a “burn wave” that propagates outward through cold fuel. For typical fuel masses, the ρR must be increased by a factor of about twenty over “normal”, solid D-T values to simply support a burn propagation wave and over a factor of one hundred to attain optimal burn conditions (This later condition corresponds to increasing the fuel density by about a factor of a thousand over solid density). Thus, the ρR attained in a pellet implosion is an extremely critical measure of pellet performance [35].

Unfortunately, ρR is a difficult quantity to measure. One potential way to measure the ρR of D-T fuel is to measure the neutron “down scattered fraction” or dsf . Most of the 14.1 MeV neutrons born in the fusion reactions escape the fuel without interacting. If high ρR s are attained, however, a small fraction of the neutrons will down-scatter in the fuel and exit the fuel with energies lower than the initial 14.1 MeV that they are born with. The fraction of scattered neutrons observed will be a measure of the fuel ρR , so if the dsf can be measured, the fuel ρR can be calculated. Since the scattered neutrons have less energy, they will travel more slowly to the nTOF detector so the detector’s response to these neutrons will be separated in time from those of the primary pulse which will allow their measurement. However, the fact that the scattered neutrons will have lower energies also means that, neutron for neutron, they will induce less light output in the nTOF detector. Thus, to get the true dsf the light output of the respective signals must be adjusted for neutron energy – something that can be readily accomplished by the use of the techniques described herein.

These techniques can also be applied to ρR measurements of D-D fusion experiments. In the case of D-D fusion there are two reactions of roughly equal probability:



The product tritium of equation 36 can react with the deuterium fuel and drive the D-T reaction above (equation 34). The ratio of D-D to D-T reactions is a function of the ρR of the fuel, so measuring the ratio of D-D to D-T neutrons will give a measure of the fuel

ρR . As above, the difference in energies of the 2.45 MeV D-D neutrons and the 14.1 MeV D-T neutrons means that the two signals will be well-separated in time at an nTOF detector. Again, by properly adjusting the light output of the two signals for the different neutron energies using the techniques described in this dissertation, the ratio of D-D to D-T reactions can be measured, which, in turn will yield the fuel ρR .

ICF applications are also requiring scintillators with ever-faster time responses. This need leads to the introduction of novel scintillation materials. For example, the primary *dsf* nTOF detector at NIF uses xylene as the scintillation material. This material (or other “exotic” materials that might be used) may not have the same light output curve as typical plastic scintillators (equations 2 and 3, page 10; also Figure 7, page 11). Thus, to fully generalize the techniques discussed herein will require the experimental verification of the light output curves of all the scintillation materials being used.

The technique described herein has also been used to model the effectiveness of a new collimator design. It has been shown that the addition of a collimator did indeed improve the neutron signals but there was still room for improvement. Therefore, a new collimator design was undertaken, to be more massive than the first, and was shown with modeling that it was much more effective at eliminating neutrons that would contribute to scattering into the detectors later in time. This is shown in full in Appendix F.

APPENDICIES

APPENDIX A

MCNP-PoliMi INPUT DECK

INPUT DECK

```

C
C      BOTTOM nTOF W/ TIVAR COLLIMATOR
C
C      CELLS:
1      0 905 -1 -23
2      4 -8.96 1 -2 -11 665
3      4 -8.96 1 -2 11 -12
4      0 2 -3 -12
5      4 -8.96 3 -4 -11 665
6      4 -8.96 3 -4 11 -12
7      0 4 -5 -12
8      4 -8.96 5 -6 -11 665
9      4 -8.96 5 -6 11 -12
10     0 6 -7 -12
11     4 -8.96 7 -8 -11 665
12     4 -8.96 7 -8 11 -12
13     0 8 -9 -23
14     0 9 -10 -11
15     1 -7.9 9 -10 11 -12
16     1 -7.9 9 -10 12 -23
17     1 -7.9 9 -10 -22 23
18     1 -7.9 10 -13 -24 25
19     1 -7.9 10 -13 24 -12
20     1 -7.9 10 -13 12 -23
21     1 -7.9 10 -13 23 -22
C
22     2 -19.2 13 -27 25 -24 $ *****
23     2 -19.2 27 -28 25 -24
24     2 -19.2 28 -29 25 -24
25     2 -19.2 29 -30 25 -24
26     2 -19.2 30 -31 25 -24 $ Tungsten Insert
27     2 -19.2 31 -32 25 -24
28     2 -19.2 32 -33 25 -24
29     2 -19.2 33 -34 25 -24
30     2 -19.2 34 -35 25 -24
31     2 -19.2 35 -36 25 -24 $ *****
C
32     3 -0.93 13 -27 24 -12 $ TIVAR COLLIMATOR
33     3 -0.93 13 -27 12 -141
34     3 -0.93 27 -28 24 -12
35     3 -0.93 27 -28 12 -141
36     3 -0.93 28 -29 24 -12
37     3 -0.93 28 -29 12 -141
38     3 -0.93 29 -30 24 -12
39     3 -0.93 29 -30 12 -141
40     3 -0.93 30 -31 24 -12
41     3 -0.93 30 -31 12 -141
42     3 -0.93 31 -32 24 -12
43     3 -0.93 31 -32 12 -141
44     3 -0.93 32 -33 24 -12
45     3 -0.93 32 -33 12 -758
46     3 -0.93 33 -34 24 -12
47     3 -0.93 33 -34 12 -758
48     3 -0.93 34 -35 24 -12
49     3 -0.93 34 -35 12 -758
50     3 -0.93 35 -36 24 -12
51     3 -0.93 35 -36 12 -758 $ TIVAR COLLIMATOR
C
52     0 46 -74 -23 $ Void Inside Collimator Cone
C
53     2 -19.2 36 -37 25 -24 $ *****
C
54     3 -0.93 36 -37 24 -12

```

55	3	-0.93	36	-37	12	-140	
56	3	-0.93	36	-37	140	-758	
C							
57	2	-19.2	37	-38	25	-24	
C							
58	3	-0.93	37	-38	24	-12	
59	3	-0.93	37	-38	12	-140	
60	3	-0.93	37	-38	140	-758	
C							
61	2	-19.2	38	-39	25	-24	\$ Part of 10" Tungsten Insert
C							
62	3	-0.93	38	-39	24	-12	
63	3	-0.93	38	-39	12	-140	
64	3	-0.93	38	-39	140	-758	
C							
65	2	-19.2	39	-40	25	-24	
C							
66	3	-0.93	39	-40	24	-12	
67	3	-0.93	39	-40	12	-140	
68	3	-0.93	39	-40	140	-758	
C							
69	2	-19.2	40	-41	25	-24	\$ Part of 10" Tungsten Insert
C							
70	3	-0.93	40	-41	24	-12	
71	3	-0.93	40	-41	12	-140	
72	3	-0.93	40	-41	140	-758	
C							
73	2	-19.2	41	-42	25	-24	\$ Part of 10" Tungsten Insert
C							
74	3	-0.93	41	-42	24	-12	
75	3	-0.93	41	-42	12	-140	
76	3	-0.93	41	-42	140	-758	
C							
77	2	-19.2	42	-43	25	-24	\$ Part of 10" Tungsten Insert
C							
78	3	-0.93	42	-43	24	-12	
79	3	-0.93	42	-43	12	-140	
80	3	-0.93	42	-43	140	-758	
C							
81	2	-19.2	43	-44	25	-24	\$ Part of 10" Tungsten Insert
C							
82	3	-0.93	43	-44	24	-12	
83	3	-0.93	43	-44	12	-140	
84	3	-0.93	43	-44	140	-758	
C							
85	2	-19.2	44	-45	25	-24	\$ Part of 10" Tungsten Insert
C							
86	3	-0.93	44	-45	24	-12	
87	3	-0.93	44	-45	12	-140	
88	3	-0.93	44	-45	140	-758	
C							
89	2	-19.2	45	-46	25	-24	\$ Part of 10" Tungsten Insert
C							
90	3	-0.93	45	-46	24	-12	
91	3	-0.93	45	-46	12	-140	
92	3	-0.93	45	-46	140	-758	\$ End of 10" Tungsten/TIVAR
C							
C 93	0	46	-54	-23			
C							
C 94	0	47	-48	25	-24		
C 95	0	48	-49	25	-24		
C 96	0	49	-50	25	-24		
C 97	0	50	-51	25	-24		
C 98	0	51	-52	25	-24		
C 99	0	52	-53	25	-24		
C 100	0	53	-54	25	-24		
C							
101	0	13	-46	-25			\$ Void inside collimator
C							
C 102	0	55	-56	25	-24		\$ TIVAR Collimator
C 103	0	56	-57	25	-24		
C 104	0	57	-58	25	-24		

C 105	0	58	-59	25	-24	
C 106	0	59	-60	25	-24	
C 107	0	60	-61	25	-24	
C 108	0	61	-62	25	-24	
C 109	0	62	-63	25	-24	
C 110	0	63	-64	25	-24	
C 111	0	64	-65	25	-24	
C 112	0	65	-66	25	-24	\$ *****
C						
C 113	0	46	-47	24	-142	\$ *****
C 114	0	46	-47	142	-140	
C 115	0	46	-47	140	-141	
C 116	0	47	-48	24	-142	
C 117	0	47	-48	142	-140	
C 118	0	47	-48	140	-141	
C 119	0	48	-49	24	-142	
C 120	0	48	-49	142	-140	
C 121	0	48	-49	140	-141	
C 122	0	49	-50	24	-142	
C 123	0	49	-50	142	-140	
C 124	0	49	-50	140	-141	
C 125	0	50	-51	24	-142	\$ Cells where more TIVAR
C 126	0	50	-51	142	-140	\$ can be added to the
C 127	0	50	-51	140	-141	\$ 25.4 cm (10 in) length
C 128	0	51	-52	24	-142	
C 129	0	51	-52	142	-140	
C 130	0	51	-52	140	-141	
C 131	0	52	-53	24	-142	
C 132	0	52	-53	142	-140	
C 133	0	52	-53	140	-141	
C 134	0	53	-54	24	-142	
C 135	0	53	-54	142	-140	
C 136	0	53	-54	140	-141	\$ *****
C						
C 137	0	66	-74	-23		\$ *****
C 138	0	139	-67	25	-24	
C 139	0	139	-67	24	-142	
C 140	0	67	-68	-25		
C 141	0	67	-68	25	-24	
C 142	0	67	-68	24	-142	
C 143	0	68	-69	-25		
C 144	0	68	-69	25	-24	
C 145	0	68	-69	24	-142	
C 146	0	69	-70	-25		
C 147	0	69	-70	25	-24	
C 148	0	69	-70	24	-142	\$ Cells where more TIVAR
C 149	0	70	-71	-25		\$ can be added to the
C 150	0	70	-71	25	-24	\$ 50.8 cm (20 in) length
C 151	0	70	-71	24	-142	
C 152	0	71	-72	-25		
C 153	0	71	-72	25	-24	
C 154	0	71	-72	24	-142	
C 155	0	72	-73	-25		
C 156	0	72	-73	25	-24	
C 157	0	72	-73	24	-142	
C 158	0	73	-74	-25		
C 159	0	73	-74	25	-24	
C 160	0	73	-74	24	-142	\$ *****
C						
C 161	0	54	-66	142	-23	
C						
162	1	-7.9	13	-27	23	-22 \$ *****
163	1	-7.9	27	-28	23	-22
164	1	-7.9	28	-29	23	-22
165	1	-7.9	29	-30	23	-22
166	1	-7.9	30	-31	23	-22
167	1	-7.9	31	-32	23	-22
168	1	-7.9	32	-33	23	-22
169	1	-7.9	33	-34	23	-22
170	1	-7.9	34	-35	23	-22
171	1	-7.9	35	-36	23	-22
172	1	-7.9	36	-37	23	-22

173	1	-7.9	37	-38	23	-22
174	1	-7.9	38	-39	23	-22
175	1	-7.9	39	-40	23	-22
176	1	-7.9	40	-41	23	-22
177	1	-7.9	41	-42	23	-22
178	1	-7.9	42	-43	23	-22
179	1	-7.9	43	-44	23	-22
180	1	-7.9	44	-45	23	-22
181	1	-7.9	45	-46	23	-22
182	1	-7.9	46	-47	23	-22
183	1	-7.9	47	-48	23	-22
184	1	-7.9	48	-49	23	-22
185	1	-7.9	49	-50	23	-22
186	1	-7.9	50	-51	23	-22
187	1	-7.9	51	-52	23	-22
188	1	-7.9	52	-53	23	-22
189	1	-7.9	53	-54	23	-22
190	1	-7.9	54	-55	23	-22
191	1	-7.9	55	-56	23	-22
192	1	-7.9	56	-57	23	-22
193	1	-7.9	57	-58	23	-22
194	1	-7.9	58	-59	23	-22
195	1	-7.9	59	-60	23	-22
196	1	-7.9	60	-61	23	-22
197	1	-7.9	61	-62	23	-22
198	1	-7.9	62	-63	23	-22
199	1	-7.9	63	-64	23	-22
200	1	-7.9	64	-65	23	-22
201	1	-7.9	65	-66	23	-22
202	1	-7.9	66	-67	23	-22
203	1	-7.9	67	-68	23	-22
204	1	-7.9	68	-69	23	-22
205	1	-7.9	69	-70	23	-22
206	1	-7.9	70	-71	23	-22
207	1	-7.9	71	-72	23	-22
208	1	-7.9	72	-73	23	-22
209	1	-7.9	73	-74	23	-22
210	1	-7.9	74	-75	23	-22
211	1	-7.9	75	-76	23	-22
212	1	-7.9	76	-77	23	-22
213	1	-7.9	77	-78	23	-22
214	1	-7.9	78	-79	23	-22
215	1	-7.9	79	-80	23	-22
216	1	-7.9	80	-81	23	-22
217	1	-7.9	81	-82	23	-22
218	1	-7.9	82	-83	23	-22
219	1	-7.9	83	-84	23	-22
220	1	-7.9	84	-85	23	-22
221	1	-7.9	85	-86	23	-22
222	1	-7.9	86	-87	23	-22
223	1	-7.9	87	-88	23	-22
224	1	-7.9	88	-89	23	-22
225	1	-7.9	89	-90	23	-22
226	1	-7.9	90	-91	23	-22
227	1	-7.9	91	-92	23	-22
228	1	-7.9	92	-93	23	-22
229	1	-7.9	93	-94	23	-22
230	1	-7.9	94	-95	23	-22
231	1	-7.9	95	-96	23	-22
232	1	-7.9	96	-97	23	-22
233	1	-7.9	97	-98	23	-22
234	1	-7.9	98	-99	23	-22
235	1	-7.9	99	-100	23	-22
236	1	-7.9	100	-101	23	-22
237	1	-7.9	101	-102	23	-22
238	1	-7.9	102	-103	23	-22
239	1	-7.9	103	-104	23	-22
240	1	-7.9	104	-105	23	-22
241	1	-7.9	105	-106	23	-22
242	1	-7.9	106	-107	23	-22
243	1	-7.9	107	-108	23	-22
244	1	-7.9	108	-109	23	-22

\$ MITL Cone

245	1	-7.9	109	-110	23	-22	
246	1	-7.9	110	-111	23	-22	
247	1	-7.9	111	-112	23	-22	
248	1	-7.9	112	-113	23	-22	
249	1	-7.9	113	-114	23	-22	
250	1	-7.9	114	-115	23	-22	
251	1	-7.9	115	-116	23	-22	
252	1	-7.9	116	-117	23	-22	
253	1	-7.9	117	-16	23	-22	\$ *****
C							
254	1	-7.9	16	-119	20	-21	\$ *****
255	1	-7.9	119	-120	20	-21	
256	1	-7.9	120	-121	20	-21	
257	1	-7.9	121	-122	20	-21	
258	1	-7.9	122	-123	20	-21	
259	1	-7.9	123	-124	20	-21	
260	1	-7.9	124	-125	20	-21	
261	1	-7.9	125	-126	20	-21	\$ Bottom Cylinder of MITLs
262	1	-7.9	126	-127	20	-21	
263	1	-7.9	127	-128	20	-21	
264	1	-7.9	128	-129	20	-21	
265	1	-7.9	129	-130	20	-21	
266	1	-7.9	130	-131	20	-21	
267	1	-7.9	131	-132	20	-21	
268	1	-7.9	132	-133	20	-21	
269	1	-7.9	133	-134	20	-21	
270	1	-7.9	134	-135	20	-21	
271	1	-7.9	135	-17	20	-21	\$ *****
C							
C 272	0	9	-17	22	-21		\$ Don't need -- see cell 481
C 273	0	106	-106	-25			\$ Inside Collimator Cone (25)
274	0	106	-16	-23			
275	0	16	-17	-20			
C							
276	6	-1.032	18	-460	-137		\$ TOP nTOF Scintillator Cell
C							Either BC-418 or BC-422Q --
C							Same Density and Ratio
C							
277	0	671	-672	137	-931		\$ Pig Cell
C 278	0	66	-139	-25			\$ Tally Cell at Collimator Exit
C 279	0	66	-139	25	-24		
C 280	0	66	-139	24	-142		
C							
C 281	0	1	-3	144	-146		\$ *****
C 282	0	3	-5	144	-146		\$ Void Cells around outside
C 283	0	5	-7	144	-146		\$ of MITL Cone (22 & 23)
C 284	0	7	-9	144	-146		\$ *****
C							
285	0	17	-149	-20			
C							
286	0	434	-430	680	-21	#2291	
C							
287	0	13	-32	141	-23		
C 288	0	27	-28	141	-23		
C 289	0	28	-29	141	-23		
C 290	0	29	-30	141	-23		
C 291	0	30	-31	141	-23		
C 292	0	31	-32	141	-23		
C							
C 293	0	32	-33	141	-23		
C 294	0	33	-34	141	-23		
C 295	0	34	-35	141	-23		
C 296	0	35	-36	141	-23		
C 297	0	36	-37	141	-23		
C 298	0	37	-38	141	-23		
C 299	0	38	-39	141	-23		
C 300	0	39	-40	141	-23		
C 301	0	40	-41	141	-23		
C 302	0	41	-42	141	-23		
C 303	0	42	-43	141	-23		
C 304	0	43	-44	141	-23		
C 305	0	44	-45	141	-23		

```

c 306 0 45 -46 141 -23
c
c 307 0 46 -47 141 -23
c 308 0 47 -48 141 -23
c 309 0 48 -49 141 -23
c 310 0 49 -50 141 -23
c 311 0 50 -51 141 -23
c 312 0 51 -52 141 -23
c 313 0 52 -53 141 -23
c 314 0 53 -54 141 -23
c
c 315 0 54 -55 24 -142 $ *****
c 316 0 55 -56 24 -142
c 317 0 56 -57 24 -142
c 318 0 57 -58 24 -142
c 319 0 58 -59 24 -142 $ More Tivar to "Shadow" the
c 320 0 59 -60 24 -142 $ pig to twice it's radius
c 321 0 60 -61 24 -142 $ (from 54.61 cm to 109.22 cm)
c 322 0 61 -62 24 -142
c 323 0 62 -63 24 -142
c 324 0 63 -64 24 -142
c 325 0 64 -65 24 -142
c 326 0 65 -66 24 -142 $ *****
c
c 327 0 66 -139 142 -23
c 328 0 139 -74 142 -23
c 329 0 67 -68 142 -23
c 330 0 68 -69 142 -23
c 331 0 69 -70 142 -23
c 332 0 70 -71 142 -23
c 333 0 71 -72 142 -23
c 334 0 72 -73 142 -23
c 335 0 73 -74 142 -23
c
336 0 74 -106 -23 $ *****
c 337 0 74 -75 25 -24
c 338 0 74 -75 24 -142
c 339 0 74 -75 142 -23
c 340 0 75 -76 -25
c 341 0 75 -76 25 -24
c 342 0 75 -76 24 -142
c 343 0 75 -76 142 -23
c 344 0 76 -77 -25
c 345 0 76 -77 25 -24
c 346 0 76 -77 24 -142
c 347 0 76 -77 142 -23
c 348 0 77 -78 -25
c 349 0 77 -78 25 -24
c 350 0 77 -78 24 -142
c 351 0 77 -78 142 -23
c 352 0 78 -79 -25
c 353 0 78 -79 25 -24
c 354 0 78 -79 24 -142
c 355 0 78 -79 142 -23
c 356 0 79 -80 -25
c 357 0 79 -80 25 -24
c 358 0 79 -80 24 -142
c 359 0 79 -80 142 -23
c 360 0 80 -81 -25
c 361 0 80 -81 25 -24
c 362 0 80 -81 24 -142
c 363 0 80 -81 142 -23
c 364 0 81 -82 -25
c 365 0 81 -82 25 -24
c 366 0 81 -82 24 -142
c 367 0 81 -82 142 -23
c 368 0 82 -83 -25
c 369 0 82 -83 25 -24
c 370 0 82 -83 24 -142
c 371 0 82 -83 142 -23
c 372 0 83 -84 -25
c 373 0 83 -84 25 -24

```

C 374	0 83 -84 24 -142	
C 375	0 83 -84 142 -23	
C 376	0 84 -85 -25	
C 377	0 84 -85 25 -24	\$ Cells where more TIVAR
C 378	0 84 -85 24 -142	\$ Can be added to Collimator
C 379	0 84 -85 142 -23	
C 380	0 85 -86 -25	
C 381	0 85 -86 25 -24	
C 382	0 85 -86 24 -142	
C 383	0 85 -86 142 -23	
C 384	0 86 -87 -25	
C 385	0 86 -87 25 -24	
C 386	0 86 -87 24 -142	
C 387	0 86 -87 142 -23	
C 388	0 87 -88 -25	
C 389	0 87 -88 25 -24	
C 390	0 87 -88 24 -142	
C 391	0 87 -88 142 -23	
C 392	0 88 -89 -25	
C 393	0 88 -89 25 -24	
C 394	0 88 -89 24 -142	
C 395	0 88 -89 142 -23	
C 396	0 89 -90 -25	
C 397	0 89 -90 25 -24	
C 398	0 89 -90 24 -142	
C 399	0 89 -90 142 -23	
C 400	0 90 -91 -25	
C 401	0 90 -91 25 -24	
C 402	0 90 -91 24 -142	
C 403	0 90 -91 142 -23	
C 404	0 91 -92 -25	
C 405	0 91 -92 25 -24	
C 406	0 91 -92 24 -142	
C 407	0 91 -92 142 -23	
C 408	0 92 -93 -25	
C 409	0 92 -93 25 -24	
C 410	0 92 -93 24 -142	
C 411	0 92 -93 142 -23	
C 412	0 93 -94 -25	
C 413	0 93 -94 25 -24	
C 414	0 93 -94 24 -142	
C 415	0 93 -94 142 -23	
C 416	0 94 -95 -25	
C 417	0 94 -95 25 -24	
C 418	0 94 -95 24 -142	
C 419	0 94 -95 142 -23	
C 420	0 95 -96 -25	
C 421	0 95 -96 25 -24	
C 422	0 95 -96 24 -142	
C 423	0 95 -96 142 -23	
C 424	0 96 -97 -25	
C 425	0 96 -97 25 -24	
C 426	0 96 -97 24 -142	
C 427	0 96 -97 142 -23	
C 428	0 97 -98 -25	
C 429	0 97 -98 25 -24	
C 430	0 97 -98 24 -142	
C 431	0 97 -98 142 -23	
C 432	0 98 -99 -25	
C 433	0 98 -99 25 -24	
C 434	0 98 -99 24 -142	
C 435	0 98 -99 142 -23	
C 436	0 99 -100 -25	
C 437	0 99 -100 25 -24	
C 438	0 99 -100 24 -142	
C 439	0 99 -100 142 -23	
C 440	0 100 -101 -25	
C 441	0 100 -101 25 -24	
C 442	0 100 -101 24 -142	
C 443	0 100 -101 142 -23	
C 444	0 101 -102 -25	
C 445	0 101 -102 25 -24	

```

C 446 0 101 -102 24 -142
C 447 0 101 -102 142 -23
C 448 0 102 -103 -25
C 449 0 102 -103 25 -24
C 450 0 102 -103 24 -142
C 451 0 102 -103 142 -23
C 452 0 103 -104 -25
C 453 0 103 -104 25 -24
C 454 0 103 -104 24 -142
C 455 0 103 -104 142 -23
C 456 0 104 -105 -25
C 457 0 104 -105 25 -24
C 458 0 104 -105 24 -142
C 459 0 104 -105 142 -23
C 460 0 105 -106 -25
C 461 0 105 -106 25 -24
C 462 0 105 -106 24 -142
C 463 0 105 -106 142 -23
C
C 464 0 671 -672 669 -25
C
465 1 -7.9 1 -2 23 -22
466 1 -7.9 2 -3 23 -22
467 1 -7.9 3 -4 23 -22
468 1 -7.9 4 -5 23 -22
469 1 -7.9 5 -6 23 -22
470 1 -7.9 6 -7 23 -22
471 1 -7.9 7 -8 23 -22
472 1 -7.9 8 -9 23 -22
C
473 0 1 -8 12 -23
C
C 474 0 3 -4 12 -23
C 475 0 5 -6 12 -23
C 476 0 7 -8 12 -23
C
C 477 0 2 -3 22 -143
C 478 0 4 -5 22 -143
C 479 0 6 -7 22 -143
C 480 0 8 -9 22 -143
C
481 0 909 -145 144 -146
482 0 908 -16 22 -143
483 0 16 -145 21 -143
484 0 145 -149 21 -146
485 0 149 -675 -146
C
486 0 663 -734 -147
C
487 1 -7.9 1 -2 143 -144
488 1 -7.9 2 -3 143 -144
489 1 -7.9 3 -4 143 -144
490 1 -7.9 4 -5 143 -144
491 1 -7.9 5 -6 143 -144
492 1 -7.9 6 -7 143 -144
493 1 -7.9 7 -8 143 -144
494 1 -7.9 8 -9 143 -144
495 1 -7.9 9 -10 143 -144
496 1 -7.9 10 -13 143 -144
497 1 -7.9 13 -27 143 -144
498 1 -7.9 27 -28 143 -144
499 1 -7.9 28 -29 143 -144
500 1 -7.9 29 -30 143 -144
501 1 -7.9 30 -31 143 -144
502 1 -7.9 31 -32 143 -144
503 1 -7.9 32 -33 143 -144
504 1 -7.9 33 -34 143 -144
505 1 -7.9 34 -35 143 -144
506 1 -7.9 35 -36 143 -144
507 1 -7.9 36 -37 143 -144
508 1 -7.9 37 -38 143 -144
509 1 -7.9 38 -39 143 -144

```

\$ *****
\$ Ring around Scintillator the size
of collimator hole
\$ *****
\$ *****
\$ Void Cells on inside top
\$ of MITL Cone (22 & 23)
\$ Void Cells on outside top
\$ of MITL Cone (22 & 23)
\$ Void b/w 2nd MITL Cone and Stack
\$ Void b/w 1st & 2nd MITL Cone
\$ Void b/w MITL Cyl #1 and Stack
\$ Void b/w MITL #1 & Bottom of Stack
\$ Void b/w Stack and Detector
\$ *****

510	1	-7.9	39	-40	143	-144
511	1	-7.9	40	-41	143	-144
512	1	-7.9	41	-42	143	-144
513	1	-7.9	42	-43	143	-144
514	1	-7.9	43	-44	143	-144
515	1	-7.9	44	-45	143	-144
516	1	-7.9	45	-46	143	-144
517	1	-7.9	46	-47	143	-144
518	1	-7.9	47	-48	143	-144
519	1	-7.9	48	-49	143	-144
520	1	-7.9	49	-50	143	-144
521	1	-7.9	50	-51	143	-144
522	1	-7.9	51	-52	143	-144
523	1	-7.9	52	-53	143	-144
524	1	-7.9	53	-54	143	-144
525	1	-7.9	54	-55	143	-144
526	1	-7.9	55	-56	143	-144
527	1	-7.9	56	-57	143	-144
528	1	-7.9	57	-58	143	-144
529	1	-7.9	58	-59	143	-144
530	1	-7.9	59	-60	143	-144
531	1	-7.9	60	-61	143	-144
532	1	-7.9	61	-62	143	-144
533	1	-7.9	62	-63	143	-144
534	1	-7.9	63	-64	143	-144
535	1	-7.9	64	-65	143	-144
536	1	-7.9	65	-66	143	-144
537	1	-7.9	66	-67	143	-144
538	1	-7.9	67	-68	143	-144
539	1	-7.9	68	-69	143	-144
540	1	-7.9	69	-70	143	-144
541	1	-7.9	70	-71	143	-144
542	1	-7.9	71	-72	143	-144
543	1	-7.9	72	-73	143	-144
544	1	-7.9	73	-74	143	-144
545	1	-7.9	74	-75	143	-144
546	1	-7.9	75	-76	143	-144
547	1	-7.9	76	-77	143	-144
548	1	-7.9	77	-78	143	-144
549	1	-7.9	78	-79	143	-144
550	1	-7.9	79	-80	143	-144
551	1	-7.9	80	-81	143	-144
552	1	-7.9	81	-82	143	-144
553	1	-7.9	82	-83	143	-144
554	1	-7.9	83	-84	143	-144
555	1	-7.9	84	-85	143	-144
556	1	-7.9	85	-86	143	-144
557	1	-7.9	86	-87	143	-144
558	1	-7.9	87	-88	143	-144
559	1	-7.9	88	-89	143	-144
560	1	-7.9	89	-90	143	-144
561	1	-7.9	90	-91	143	-144
562	1	-7.9	91	-92	143	-144
563	1	-7.9	92	-93	143	-144
564	1	-7.9	93	-94	143	-144
565	1	-7.9	94	-95	143	-144
566	1	-7.9	95	-96	143	-144
567	1	-7.9	96	-97	143	-144
568	1	-7.9	97	-98	143	-144
569	1	-7.9	98	-99	143	-144
570	1	-7.9	99	-100	143	-144
571	1	-7.9	100	-101	143	-144
572	1	-7.9	101	-102	143	-144
573	1	-7.9	102	-103	143	-144
574	1	-7.9	103	-104	143	-144
575	1	-7.9	104	-105	143	-144
576	1	-7.9	105	-106	143	-144
577	1	-7.9	106	-107	143	-144
578	1	-7.9	107	-108	143	-144
579	1	-7.9	108	-109	143	-144
580	1	-7.9	109	-110	143	-144
581	1	-7.9	110	-111	143	-144

\$ 2nd MITL CONE

```

582 1 -7.9 111 -112 143 -144
583 1 -7.9 112 -113 143 -144
584 1 -7.9 113 -114 143 -144
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C 630 0 149 -148 146 -147
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\$ *****
\$ *****
\$ Cylinder Extention on MITL #1
\$ *****
\$ Stack
\$ Void at end to cover expansion
of Stack
\$ *****

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1000	1	-7.9	396	-397	146	-147
1001	1	-7.9	397	-398	146	-147
1002	1	-7.9	398	-399	146	-147
1003	1	-7.9	399	-400	146	-147
1004	1	-7.9	400	-401	146	-147
1005	1	-7.9	401	-402	146	-147
1006	1	-7.9	402	-403	146	-147
1007	1	-7.9	403	-404	146	-147

1008	1	-7.9	404	-405	146	-147	
1009	1	-7.9	405	-406	146	-147	
1010	1	-7.9	406	-407	146	-147	
1011	1	-7.9	407	-408	146	-147	
1012	1	-7.9	408	-409	146	-147	
1013	1	-7.9	409	-410	146	-147	
1014	1	-7.9	410	-411	146	-147	
1015	1	-7.9	411	-412	146	-147	
1016	1	-7.9	412	-413	146	-147	
1017	1	-7.9	413	-414	146	-147	
1018	1	-7.9	414	-415	146	-147	
1019	1	-7.9	415	-416	146	-147	
1020	1	-7.9	416	-417	146	-147	
1021	1	-7.9	417	-418	146	-147	
1022	1	-7.9	418	-419	146	-147	
1023	1	-7.9	419	-420	146	-147	
1024	1	-7.9	420	-421	146	-147	
1025	1	-7.9	421	-422	146	-147	
1026	1	-7.9	422	-423	146	-147	
1027	1	-7.9	423	-424	146	-147	
1028	1	-7.9	424	-425	146	-147	
1029	1	-7.9	425	-426	146	-147	
1030	1	-7.9	426	-427	146	-147	
1031	1	-7.9	427	-148	146	-147	\$ *****
c							
1032	2	-19.2	434	-435	431	-432	
1033	2	-19.2	435	-436	431	-432	
1034	2	-19.2	436	-437	431	-432	
1035	2	-19.2	437	-438	431	-432	
1036	2	-19.2	438	-439	431	-432	
1037	2	-19.2	439	-440	431	-432	
1038	2	-19.2	440	-441	431	-432	
1039	2	-19.2	441	-442	431	-432	
1040	2	-19.2	442	-443	431	-432	
1041	2	-19.2	443	-444	431	-432	
1042	2	-19.2	444	-445	431	-432	
1043	2	-19.2	445	-18	431	-432	
1044	2	-19.2	18	-460	431	-432	
1045	2	-19.2	460	-446	431	-432	
1046	2	-19.2	446	-447	431	-432	
1047	2	-19.2	447	-448	431	-432	
1048	2	-19.2	448	-449	431	-432	
1049	2	-19.2	449	-428	431	-432	
1050	2	-19.2	428	-429	431	-432	
c 1051	5	-11.34	428	-429	459	-431	
1052	5	-11.34	428	-429	458	-431	
1053	5	-11.34	428	-429	457	-458	
1054	5	-11.34	428	-429	456	-457	
1055	5	-11.34	428	-429	455	-456	
1056	5	-11.34	428	-429	454	-455	
1057	5	-11.34	428	-429	453	-454	
1058	5	-11.34	428	-429	452	-453	
1059	5	-11.34	428	-429	451	-452	
1060	5	-11.34	428	-429	450	-451	
1061	5	-11.34	428	-429	137	-450	
1062	5	-11.34	428	-429	461	-137	
c							
1063	5	-11.34	434	-435	432	-433	
1064	5	-11.34	435	-436	432	-433	
1065	5	-11.34	436	-437	432	-433	
1066	5	-11.34	437	-438	432	-433	
1067	5	-11.34	438	-439	432	-433	
1068	5	-11.34	439	-440	432	-433	
1069	5	-11.34	440	-441	432	-433	
1070	5	-11.34	441	-442	432	-433	
1071	5	-11.34	442	-443	432	-433	
1072	5	-11.34	443	-444	432	-433	
1073	5	-11.34	444	-445	432	-433	
1074	5	-11.34	445	-18	432	-433	
1075	5	-11.34	18	-460	432	-433	
1076	5	-11.34	460	-446	432	-433	
1077	5	-11.34	446	-447	432	-433	

```

1078 5 -11.34 447 -448 432 -433
1079 5 -11.34 448 -449 432 -433
1080 5 -11.34 449 -428 432 -433
1081 5 -11.34 428 -429 432 -433
1082 5 -11.34 429 -430 432 -433
1083 2 -19.2 429 -430 431 -432
c 1084 2 -19.2 429 -430 459 -431
1085 2 -19.2 429 -430 458 -431
1086 2 -19.2 429 -430 457 -458
1087 2 -19.2 429 -430 456 -457
1088 2 -19.2 429 -430 455 -456
1089 2 -19.2 429 -430 454 -455
1090 2 -19.2 429 -430 453 -454
1091 2 -19.2 429 -430 452 -453
1092 2 -19.2 429 -430 451 -452
1093 2 -19.2 429 -430 450 -451
1094 2 -19.2 429 -430 137 -450
1095 2 -19.2 429 -430 461 -137
c
1096 0 471 -671 -431
1097 0 672 -428 -431
c
1098 5 -11.34 428 -429 -461
1099 2 -19.2 429 -430 -461
c
c 1100 2 -19.2 462 -463 431 -432
c 1101 2 -19.2 463 -464 431 -432
c 1102 2 -19.2 464 -465 431 -432
c 1103 2 -19.2 465 -466 431 -432
c 1104 2 -19.2 466 -467 431 -432
c 1105 2 -19.2 467 -468 431 -432
c 1106 2 -19.2 468 -469 431 -432
c 1107 2 -19.2 469 -470 431 -432
c 1108 2 -19.2 470 -471 431 -432
c
1109 2 -19.2 471 -472 431 -432
1110 2 -19.2 472 -473 431 -432
1111 2 -19.2 473 -474 431 -432
1112 2 -19.2 474 -475 431 -432
1113 2 -19.2 475 -476 431 -432
1114 2 -19.2 476 -477 431 -432
1115 2 -19.2 477 -478 431 -432
1116 2 -19.2 478 -479 431 -432
1117 2 -19.2 479 -480 431 -432
1118 2 -19.2 480 -481 431 -432
1119 2 -19.2 481 -434 431 -432
c
c 1120 5 -11.34 462 -463 432 -433
c 1121 5 -11.34 463 -464 432 -433
c 1122 5 -11.34 464 -465 432 -433
c 1123 5 -11.34 465 -466 432 -433
c 1124 5 -11.34 466 -467 432 -433
c 1125 5 -11.34 467 -468 432 -433
c 1126 5 -11.34 468 -469 432 -433
c 1127 5 -11.34 469 -470 432 -433
c 1128 5 -11.34 470 -471 432 -433
c
1129 5 -11.34 471 -472 432 -433
1130 5 -11.34 472 -473 432 -433
1131 5 -11.34 473 -474 432 -433
1132 5 -11.34 474 -475 432 -433
1133 5 -11.34 475 -476 432 -433
1134 5 -11.34 476 -477 432 -433
1135 5 -11.34 477 -478 432 -433
1136 5 -11.34 478 -479 432 -433
1137 5 -11.34 479 -480 432 -433
1138 5 -11.34 480 -481 432 -433
1139 5 -11.34 481 -434 432 -433
c
1140 0 471 -434 680 -147
c
1141 2 -19.2 489 -488 431 -432 $ *****

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1142 2 -19.2 488 -487 431 -432
 1143 2 -19.2 487 -486 431 -432
 1144 2 -19.2 486 -485 431 -432
 1145 2 -19.2 485 -484 431 -432
 1146 2 -19.2 484 -483 431 -432
 1147 2 -19.2 483 -482 431 -432
 1148 2 -19.2 482 -471 431 -432
 1149 5 -11.34 489 -488 432 -433
 1150 5 -11.34 488 -487 432 -433
 1151 5 -11.34 487 -486 432 -433
 1152 5 -11.34 486 -485 432 -433
 1153 5 -11.34 485 -484 432 -433
 1154 5 -11.34 484 -483 432 -433
 1155 5 -11.34 483 -482 432 -433
 1156 5 -11.34 482 -471 432 -433
 C
 1157 5 -11.34 499 -498 137 -450
 1158 5 -11.34 499 -498 450 -451
 C
 1159 1 -7.9 499 -498 451 -452
 1160 1 -7.9 499 -498 452 -453
 1161 1 -7.9 499 -498 453 -454
 1162 1 -7.9 499 -498 454 -455
 1163 1 -7.9 499 -498 455 -456
 1164 1 -7.9 499 -498 456 -457
 1165 1 -7.9 499 -498 457 -458
 1166 1 -7.9 499 -498 458 -431
 1167 1 -7.9 499 -498 431 -432
 1168 1 -7.9 499 -498 432 -433
 C
 1169 2 -19.2 498 -497 137 -450
 1170 2 -19.2 498 -497 450 -451
 1171 2 -19.2 498 -497 451 -452
 1172 2 -19.2 498 -497 452 -453
 1173 2 -19.2 498 -497 453 -454
 1174 2 -19.2 498 -497 454 -455
 1175 2 -19.2 498 -497 455 -456
 1176 2 -19.2 498 -497 456 -457
 1177 2 -19.2 498 -497 457 -458
 1178 2 -19.2 498 -497 458 -431
 1179 2 -19.2 498 -497 431 -432
 1180 2 -19.2 498 -497 432 -433
 1181 2 -19.2 497 -496 137 -450
 1182 2 -19.2 497 -496 450 -451
 1183 2 -19.2 497 -496 451 -452
 1184 2 -19.2 497 -496 452 -453
 1185 2 -19.2 497 -496 453 -454
 1186 2 -19.2 497 -496 454 -455
 1187 2 -19.2 497 -496 455 -456
 1188 2 -19.2 497 -496 456 -457
 1189 2 -19.2 497 -496 457 -458
 1190 2 -19.2 497 -496 458 -431
 1191 2 -19.2 497 -496 431 -432
 1192 2 -19.2 497 -496 432 -433
 1193 2 -19.2 496 -495 137 -450
 1194 2 -19.2 496 -495 450 -451
 1195 2 -19.2 496 -495 451 -452
 1196 2 -19.2 496 -495 452 -453
 1197 2 -19.2 496 -495 453 -454
 1198 2 -19.2 496 -495 454 -455
 1199 2 -19.2 496 -495 455 -456
 1200 2 -19.2 496 -495 456 -457
 1201 2 -19.2 496 -495 457 -458
 1202 2 -19.2 496 -495 458 -431
 1203 2 -19.2 496 -495 431 -432
 1204 2 -19.2 496 -495 432 -678
 1205 2 -19.2 495 -494 137 -450
 1206 2 -19.2 495 -494 450 -451
 1207 2 -19.2 495 -494 451 -452
 1208 2 -19.2 495 -494 452 -453
 1209 2 -19.2 495 -494 453 -454
 1210 2 -19.2 495 -494 454 -455

\$ Pig made 8" longer for a total
 \$ length of 48"

\$ *****

\$ *****

\$ 10" TUNGSTEN PLUG WITH A 3" DIA HOLE

1211	2	-19.2	495	-494	455	-456	
1212	2	-19.2	495	-494	456	-457	
1213	2	-19.2	495	-494	457	-458	
1214	2	-19.2	495	-494	458	-431	
1215	2	-19.2	495	-494	431	-432	
1216	2	-19.2	495	-494	432	-678	
1217	2	-19.2	494	-493	137	-450	
1218	2	-19.2	494	-493	450	-451	
1219	2	-19.2	494	-493	451	-452	
1220	2	-19.2	494	-493	452	-453	
1221	2	-19.2	494	-493	453	-454	
1222	2	-19.2	494	-493	454	-455	
1223	2	-19.2	494	-493	455	-456	
1224	2	-19.2	494	-493	456	-457	
1225	2	-19.2	494	-493	457	-458	
1226	2	-19.2	494	-493	458	-431	
1227	2	-19.2	494	-493	431	-432	
1228	1	-7.9	494	-493	432	-678	
1229	2	-19.2	493	-492	137	-450	
1230	2	-19.2	493	-492	450	-451	
1231	2	-19.2	493	-492	451	-452	
1232	2	-19.2	493	-492	452	-453	
1233	2	-19.2	493	-492	453	-454	
1234	2	-19.2	493	-492	454	-455	
1235	2	-19.2	493	-492	455	-456	
1236	2	-19.2	493	-492	456	-457	
1237	2	-19.2	493	-492	457	-458	
1238	2	-19.2	493	-492	458	-431	
1239	2	-19.2	493	-492	431	-432	
1240	1	-7.9	493	-492	432	-678	
1241	2	-19.2	492	-491	137	-450	
1242	2	-19.2	492	-491	450	-451	
1243	2	-19.2	492	-491	451	-452	
1244	2	-19.2	492	-491	452	-453	
1245	2	-19.2	492	-491	453	-454	
1246	2	-19.2	492	-491	454	-455	
1247	2	-19.2	492	-491	455	-456	
1248	2	-19.2	492	-491	456	-457	
1249	2	-19.2	492	-491	457	-458	
1250	2	-19.2	492	-491	458	-431	
1251	1	-7.9	492	-491	431	-432	
1252	1	-7.9	492	-491	432	-433	
1253	2	-19.2	491	-490	137	-450	
1254	2	-19.2	491	-490	450	-451	
1255	2	-19.2	491	-490	451	-452	
1256	2	-19.2	491	-490	452	-453	
1257	2	-19.2	491	-490	453	-454	
1258	2	-19.2	491	-490	454	-455	
1259	2	-19.2	491	-490	455	-456	
1260	2	-19.2	491	-490	456	-457	
1261	2	-19.2	491	-490	457	-458	
1262	2	-19.2	491	-490	458	-431	
1263	1	-7.9	491	-490	431	-432	
1264	1	-7.9	491	-490	432	-433	
1265	2	-19.2	490	-937	137	-450	
1266	2	-19.2	490	-489	450	-451	
1267	2	-19.2	490	-489	451	-452	
1268	2	-19.2	490	-489	452	-453	
1269	2	-19.2	490	-489	453	-454	
1270	2	-19.2	490	-489	454	-455	
1271	2	-19.2	490	-489	455	-456	
1272	2	-19.2	490	-489	456	-457	
1273	2	-19.2	490	-489	457	-458	
1274	1	-7.9	490	-489	458	-431	
1275	1	-7.9	490	-489	431	-432	
1276	1	-7.9	490	-489	432	-433	\$ *****
	C						
1277	0	496	-489	-137			\$ 3" diameter hole thru Tungsten Plug
	C						
1278	0	668	-471	-431			\$ Void on inside of Pig
	C						
1279	0	679	-471	680	-147		\$ Void on outside of Pig

C
1280 5 -11.34 499 -498 -461 \$ *****
1281 5 -11.34 499 -498 461 -137
1282 5 -11.34 498 -497 -461
1283 5 -11.34 498 -497 461 -137 \$ 3" Pb PLUG
1284 5 -11.34 497 -496 -461
1285 5 -11.34 497 -496 461 -137 \$ *****
C
1286 1 -7.9 496 -495 678 -433
C
1287 1 -7.9 495 -494 678 -433
1288 1 -7.9 494 -493 678 -433
1289 1 -7.9 493 -492 678 -433
1290 1 -7.9 499 -498 433 -508
C 1291 5 -11.34 506 -505 451 -452
C 1292 5 -11.34 506 -505 452 -453
C 1293 5 -11.34 506 -505 453 -454
C 1294 5 -11.34 505 -504 -461
C 1295 5 -11.34 505 -504 461 -137
C 1296 5 -11.34 505 -504 137 -450
C 1297 5 -11.34 505 -504 450 -451
C 1298 5 -11.34 505 -504 451 -452
C 1299 5 -11.34 505 -504 452 -453
C 1300 5 -11.34 505 -504 453 -454
C
1301 5 -11.34 504 -503 -461
1302 5 -11.34 504 -503 461 -137
1303 5 -11.34 504 -503 137 -450
1304 5 -11.34 504 -503 450 -451
1305 5 -11.34 504 -503 451 -452
1306 5 -11.34 504 -503 452 -453
1307 5 -11.34 504 -503 453 -454
1308 5 -11.34 503 -502 -461 \$ 8 INCHES OF Pb
1309 5 -11.34 503 -502 461 -137
1310 5 -11.34 503 -502 137 -450
1311 5 -11.34 503 -502 450 -451
1312 5 -11.34 503 -502 451 -452
1313 5 -11.34 503 -502 452 -453
1314 5 -11.34 503 -502 453 -454
1315 5 -11.34 502 -501 -461
1316 5 -11.34 502 -501 461 -137
1317 5 -11.34 502 -501 137 -450
1318 5 -11.34 502 -501 450 -451
1319 5 -11.34 502 -501 451 -452
1320 5 -11.34 502 -501 452 -453
1321 5 -11.34 502 -501 453 -454
1322 5 -11.34 501 -500 -461
1323 5 -11.34 501 -500 461 -137
1324 5 -11.34 501 -500 137 -450
1325 5 -11.34 501 -500 450 -451
1326 5 -11.34 501 -500 451 -452
1327 5 -11.34 501 -500 452 -453
1328 5 -11.34 501 -500 453 -454
1329 5 -11.34 500 -499 -461
1330 5 -11.34 500 -499 461 -137
1331 5 -11.34 500 -499 137 -450
1332 5 -11.34 500 -499 450 -451
1333 5 -11.34 500 -499 451 -452
1334 5 -11.34 500 -499 452 -453
1335 5 -11.34 500 -499 453 -454 \$ *****
C
1336 0 504 -499 782 -147
C
1337 5 -11.34 489 -488 433 -508
1338 5 -11.34 488 -487 433 -508
1339 5 -11.34 487 -486 433 -508
1340 5 -11.34 486 -485 433 -508
1341 5 -11.34 485 -484 433 -508
1342 5 -11.34 484 -483 433 -508
1343 5 -11.34 483 -482 433 -508
1344 5 -11.34 482 -471 433 -508
C

c 1345 5 -11.34 462 -463 433 -508
 c 1346 5 -11.34 463 -464 433 -508
 c 1347 5 -11.34 464 -465 433 -508
 c 1348 5 -11.34 465 -466 433 -508
 c 1349 5 -11.34 466 -467 433 -508
 c 1350 5 -11.34 467 -468 433 -508
 c 1351 5 -11.34 468 -469 433 -508
 c 1352 5 -11.34 469 -470 433 -508
 c 1353 5 -11.34 470 -471 433 -508
 c
 1354 5 -11.34 471 -472 433 -508
 1355 5 -11.34 472 -473 433 -508
 1356 5 -11.34 473 -474 433 -508
 1357 5 -11.34 474 -475 433 -508
 1358 5 -11.34 475 -476 433 -508
 1359 5 -11.34 476 -477 433 -508
 1360 5 -11.34 477 -478 433 -508
 1361 5 -11.34 478 -479 433 -508
 1362 5 -11.34 479 -480 433 -508
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 1364 5 -11.34 481 -434 433 -508
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 1366 5 -11.34 435 -436 433 -508
 1367 5 -11.34 436 -437 433 -508
 1368 5 -11.34 437 -438 433 -508
 1369 5 -11.34 438 -439 433 -508
 1370 5 -11.34 439 -440 433 -508
 1371 5 -11.34 440 -441 433 -508
 1372 5 -11.34 441 -442 433 -508
 1373 5 -11.34 442 -443 433 -508
 1374 5 -11.34 443 -444 433 -508
 1375 5 -11.34 444 -445 433 -508
 1376 5 -11.34 445 -18 433 -508
 1377 5 -11.34 18 -460 433 -508
 1378 5 -11.34 460 -446 433 -508
 1379 5 -11.34 446 -447 433 -508
 1380 5 -11.34 447 -448 433 -508
 1381 5 -11.34 448 -449 433 -508
 1382 5 -11.34 449 -428 433 -508
 1383 5 -11.34 428 -429 433 -508
 1384 5 -11.34 429 -430 433 -508
 c
 1385 1 -7.9 489 -488 508 -509
 1386 1 -7.9 488 -487 508 -509
 1387 1 -7.9 487 -486 508 -509
 1388 1 -7.9 486 -485 508 -509
 1389 1 -7.9 485 -484 508 -509
 1390 1 -7.9 484 -483 508 -509
 1391 1 -7.9 483 -482 508 -509
 1392 1 -7.9 482 -471 508 -509
 c
 c 1393 1 -7.9 462 -463 508 -509
 c 1394 1 -7.9 463 -464 508 -509
 c 1395 1 -7.9 464 -465 508 -509
 c 1396 1 -7.9 465 -466 508 -509
 c 1397 1 -7.9 466 -467 508 -509
 c 1398 1 -7.9 467 -468 508 -509
 c 1399 1 -7.9 468 -469 508 -509
 c 1400 1 -7.9 469 -470 508 -509
 c 1401 1 -7.9 470 -471 508 -509
 c
 1402 1 -7.9 471 -472 508 -509
 1403 1 -7.9 472 -473 508 -509
 1404 1 -7.9 473 -474 508 -509
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 1407 1 -7.9 476 -477 508 -509
 1408 1 -7.9 477 -478 508 -509
 1409 1 -7.9 478 -479 508 -509
 1410 1 -7.9 479 -480 508 -509
 1411 1 -7.9 480 -481 508 -509
 1412 1 -7.9 481 -434 508 -509

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1413 1 -7.9 434 -435 508 -509
1414 1 -7.9 435 -436 508 -509
1415 1 -7.9 436 -437 508 -509
1416 1 -7.9 437 -438 508 -509
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1419 1 -7.9 440 -441 508 -509
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1421 1 -7.9 442 -443 508 -509
1422 1 -7.9 443 -444 508 -509
1423 1 -7.9 444 -445 508 -509
1424 1 -7.9 445 -18 508 -509
1425 1 -7.9 18 -460 508 -509
1426 1 -7.9 460 -446 508 -509
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1429 1 -7.9 448 -449 508 -509
1430 1 -7.9 449 -428 508 -509
1431 1 -7.9 428 -429 508 -509
1432 1 -7.9 429 -430 508 -509
C
1433 0 499 -498 508 -147
C
1434 1 -7.9 498 -497 508 -509
1435 1 -7.9 497 -496 508 -509
1436 1 -7.9 496 -495 508 -509
1437 1 -7.9 495 -494 508 -509
1438 1 -7.9 494 -493 508 -509
1439 1 -7.9 493 -492 508 -509
1440 1 -7.9 492 -491 508 -509
1441 1 -7.9 491 -490 508 -509
1442 1 -7.9 490 -489 508 -509
C 1443 1 -7.9 499 -498 433 -508
1444 1 -7.9 498 -497 433 -508
1445 1 -7.9 497 -496 433 -508
1446 1 -7.9 496 -495 433 -508
1447 1 -7.9 495 -494 433 -508
1448 1 -7.9 494 -493 433 -508
1449 1 -7.9 493 -492 433 -508
1450 1 -7.9 492 -491 433 -508
1451 1 -7.9 491 -490 433 -508
1452 1 -7.9 490 -489 433 -508
C
1453 0 32 -46 758 -23
C
C ***** ADDITION OF BOTTOM LID *****
C
1500 1 -7.9 600 -148 601 -146
1501 1 -7.9 600 -148 602 -601
1502 1 -7.9 600 -148 603 -602
1503 1 -7.9 600 -148 604 -603
1504 1 -7.9 600 -148 605 -604
1505 1 -7.9 600 -148 606 -605
1506 1 -7.9 600 -148 607 -606
1507 1 -7.9 600 -148 608 -607
1508 1 -7.9 600 -148 609 -608
1509 1 -7.9 600 -148 610 -609
1510 1 -7.9 600 -148 611 -610
1511 1 -7.9 600 -148 612 -611
1512 1 -7.9 600 -148 613 -612
1513 1 -7.9 600 -148 614 -613
1514 1 -7.9 600 -148 615 -614
1515 1 -7.9 600 -148 616 -615
1516 1 -7.9 600 -148 617 -616
1517 1 -7.9 600 -148 618 -617
1518 1 -7.9 600 -148 619 -618
1519 1 -7.9 600 -148 620 -619
1520 1 -7.9 600 -148 621 -620
1521 1 -7.9 600 -148 622 -621
1522 1 -7.9 600 -148 623 -622
1523 1 -7.9 600 -148 624 -623
1524 1 -7.9 600 -148 625 -624

```

1525	1	-7.9	600	-148	626	-625
1526	1	-7.9	600	-148	627	-626
1527	0	600	-148	628	-627	
1528	0	600	-148	629	-628	
1529	0	600	-148	630	-629	
1530	0	600	-148	631	-630	
1531	0	600	-148	632	-631	
1532	0	600	-148	633	-632	
1533	0	600	-148	634	-633	
1534	0	600	-148	635	-634	
1535	0	600	-148	636	-635	
1536	0	600	-148	637	-636	
1537	0	600	-148	638	-637	
1538	0	600	-148	639	-638	
1539	0	600	-148	640	-639	
1540	0	600	-148	641	-640	
1541	0	600	-148	642	-641	
1542	0	600	-148	643	-642	
1543	0	600	-148	644	-643	
1544	0	600	-148	645	-644	
1545	0	600	-148	646	-645	
1546	0	600	-148	647	-646	
1547	0	600	-148	648	-647	
1548	0	600	-148	649	-648	
1549	0	600	-148	759	-649	
1550	0	600	-148	758	-759	
1551	0	600	-148	757	-758	
1552	0	600	-148	756	-757	
1553	0	600	-148	755	-756	
1554	0	600	-148	754	-755	
1555	0	600	-148	753	-754	
1556	0	600	-148	752	-753	
1557	0	600	-148	751	-752	
1558	0	600	-148	750	-751	
1559	0	600	-148	749	-750	
1560	0	600	-148	748	-749	
1561	0	600	-148	665	-748	

\$ END OF BOTTOM LID

C

1562	8	-7.84	148	-662	625	-624
1563	8	-7.84	148	-662	626	-625
1564	8	-7.84	148	-662	627	-626
1565	8	-7.84	148	-662	628	-627
1566	8	-7.84	148	-662	629	-628
1567	8	-7.84	148	-662	630	-629
1568	8	-7.84	148	-662	631	-630
1569	8	-7.84	148	-662	632	-631
1570	8	-7.84	148	-662	633	-632
1571	8	-7.84	148	-662	634	-633
1572	8	-7.84	148	-662	635	-634
1573	8	-7.84	148	-662	636	-635
1574	8	-7.84	148	-662	637	-636
1575	8	-7.84	148	-662	638	-637
1576	8	-7.84	148	-662	639	-638
1577	8	-7.84	148	-662	640	-639
1578	8	-7.84	148	-662	641	-640
1579	8	-7.84	148	-662	642	-641
1580	8	-7.84	148	-662	643	-642
1581	8	-7.84	148	-662	644	-643
1582	8	-7.84	148	-662	645	-644
1583	8	-7.84	148	-662	646	-645
1584	8	-7.84	148	-662	647	-646
1585	8	-7.84	148	-662	648	-647
1586	8	-7.84	148	-662	649	-648
1587	8	-7.84	148	-662	759	-649
1588	8	-7.84	148	-662	758	-759
1589	8	-7.84	148	-662	757	-758
1590	8	-7.84	148	-662	756	-757
1591	8	-7.84	148	-662	755	-756
1592	8	-7.84	148	-662	754	-755
1593	8	-7.84	148	-662	753	-754
1594	8	-7.84	148	-662	752	-753
1595	8	-7.84	148	-662	751	-752

\$ 3 FOOT DIAGNOSTIC FLANGE

\$ NOTE: CHANGED FROM STAINLESS STEEL
\$ TO ORDINARY STEEL (97.96% Fe, 2.04% C)

1596 8 -7.84 148 -662 750 -751
 1597 8 -7.84 148 -662 749 -750 \$ 3 INCH RADIUS VOIDED
 1598 8 -7.84 148 -662 748 -749
 1599 8 -7.84 148 -662 665 -748
 C
 1600 8 -7.84 664 -600 628 -627 \$ 1/2" SHIELD PLATE (VACUUM SIDE)
 1601 8 -7.84 664 -600 629 -628
 1602 8 -7.84 664 -600 630 -629 \$ NOTE: CHANGED FROM STAINLESS STEEL
 1603 8 -7.84 664 -600 631 -630 \$ TO ORDINARY STEEL (97.96% Fe, 2.04% C)
 1604 8 -7.84 664 -600 632 -631
 1605 8 -7.84 664 -600 633 -632
 1606 8 -7.84 664 -600 634 -633
 1607 8 -7.84 664 -600 635 -634
 1608 8 -7.84 664 -600 636 -635
 1609 8 -7.84 664 -600 637 -636
 1610 8 -7.84 664 -600 638 -637
 1611 8 -7.84 664 -600 639 -638
 1612 8 -7.84 664 -600 640 -639
 1613 8 -7.84 664 -600 641 -640
 1614 8 -7.84 664 -600 642 -641
 1615 8 -7.84 664 -600 643 -642
 1616 8 -7.84 664 -600 644 -643
 1617 8 -7.84 664 -600 645 -644
 1618 8 -7.84 664 -600 646 -645
 1619 8 -7.84 664 -600 647 -646
 1620 8 -7.84 664 -600 648 -647
 1621 8 -7.84 664 -600 649 -648
 1622 8 -7.84 664 -600 759 -649
 1623 8 -7.84 664 -600 758 -759
 1624 8 -7.84 664 -600 757 -758
 1625 8 -7.84 664 -600 756 -757
 1626 8 -7.84 664 -600 755 -756
 1627 8 -7.84 664 -600 754 -755
 1628 8 -7.84 664 -600 753 -754
 1629 8 -7.84 664 -600 752 -753
 1630 8 -7.84 664 -600 751 -752
 1631 8 -7.84 664 -600 750 -751
 1632 8 -7.84 664 -600 749 -750
 1633 8 -7.84 664 -600 748 -749
 1634 8 -7.84 664 -600 665 -748 \$ END OF 1/2" SHIELD PLATE
 C
 C **** CHANGING PORTIONS OF BOTTOM LID TO STEEL AS OPPOSED
 C TO STAINLESS STEEL:
 C
 1635 8 -7.84 662 -663 766 -767 \$ 0.7" THICK, 8" DIA FLANGE
 1636 0 662 -663 765 -766 \$ THIS IS THE FLANGE WE
 1637 0 662 -663 764 -765 \$ "SEE" THROUGH W/ nTOF
 1638 0 662 -663 763 -764 \$ ** END OF 8" DIA FLANGE **
 C
 1639 0 664 -600 624 -146 \$ VOID B/W STACK AND 9/16" SHIELD PLATE
 1640 0 148 -662 624 -147 \$ VOID B/W OUTER STACK AND 8" FLANGE
 C
 C 1641 0 662 -507 -147 \$ VOID B/W AIR SIDE OF LID TO TOP OF 8" Pb
 C
 1642 6 -1.032 666 -667 -137 \$ TOP nTOF SCINTILLATOR
 C
 1643 7 -2.7 489 -666 -137 \$ 1/8" ALUMINUM (DETECTOR HOUSING)
 1644 7 -2.7 667 -668 -137 \$ 1/8" ALUMINUM (DETECTOR HOUSING)
 C
 1645 0 489 -668 935 -431 \$ VOID AROUND TOP nTOF INSIDE PIG
 C
 1646 8 -7.84 664 -600 -665 \$ 9/16" SHIELD PLATE
 1647 0 600 -148 -665 \$ BOTTOM LID
 1648 8 -7.84 148 -662 -665 \$ 3' DIAGNOSTIC FLANGE
 C
 C **** NOTE: STEEL AS OPPOSED TO STAINLESS STEEL:
 C
 1649 0 662 -663 -763 \$ 8" FLANGE (nTOF SEE THRU)
 C
 1650 0 662 -663 767 -147
 C
 1651 7 -2.7 489 -670 137 -935 \$ TOP nTOF ALUMINUM HOUSING

1652 7 -2.7 670 -668 137 -935 \$ TOP nTOF ALUMINUM HOUSING
 C
 1653 7 -2.7 671 -673 456 -669 929 -930 \$ OUTER LIGHTGUIDE ALUMINUM HOUSING
 1654 7 -2.7 673 -672 456 -669 929 -930 \$ OUTER LIGHTGUIDE ALUMINUM HOUSING
 1655 7 -2.7 671 -18 -137 \$ BOTTOM nTOF ALUMINUM HOUSING
 1656 7 -2.7 460 -672 -137 \$ BOTTOM nTOF ALUMINUM HOUSING
 C
 C ***** END OF BOTTOM LID ADDITION *****
 C
 C
 1657 0 10 -13 -25 \$ VOID B/L BOTTOM BLAST SHIELD
 C
 1658 0 1 -2 -665 \$ 2" HOLE THRU COPPER PLATES
 1659 0 3 -4 -665 \$ " " " " "
 1660 0 5 -6 -665 \$ " " " " "
 1661 0 7 -8 -665 \$ " " " " "
 C
 1662 4 -8.96 675 -664 628 -627 \$ 9/16" COPPER SHIELD PLATE
 1663 4 -8.96 675 -664 629 -628
 1664 4 -8.96 675 -664 630 -629
 1665 4 -8.96 675 -664 631 -630
 1666 4 -8.96 675 -664 632 -631
 1667 4 -8.96 675 -664 633 -632
 1668 4 -8.96 675 -664 634 -633
 1669 4 -8.96 675 -664 635 -634
 1670 4 -8.96 675 -664 636 -635
 1671 4 -8.96 675 -664 637 -636
 1672 4 -8.96 675 -664 638 -637
 1673 4 -8.96 675 -664 639 -638
 1674 4 -8.96 675 -664 640 -639
 1675 4 -8.96 675 -664 641 -640
 1676 4 -8.96 675 -664 642 -641
 1677 4 -8.96 675 -664 643 -642
 1678 4 -8.96 675 -664 644 -643
 1679 4 -8.96 675 -664 645 -644
 1680 4 -8.96 675 -664 646 -645
 1681 4 -8.96 675 -664 647 -646
 1682 4 -8.96 675 -664 648 -647
 1683 4 -8.96 675 -664 649 -648
 1684 4 -8.96 675 -664 759 -649
 1685 4 -8.96 675 -664 758 -759
 1686 4 -8.96 675 -664 757 -758
 1687 4 -8.96 675 -664 756 -757
 1688 4 -8.96 675 -664 755 -756
 1689 4 -8.96 675 -664 754 -755
 1690 4 -8.96 675 -664 753 -754
 1691 4 -8.96 675 -664 752 -753
 1692 4 -8.96 675 -664 751 -752
 1693 4 -8.96 675 -664 750 -751
 1694 4 -8.96 675 -664 749 -750
 1695 4 -8.96 675 -664 748 -749
 1696 4 -8.96 675 -664 665 -748
 1697 4 -8.96 675 -664 -665 \$ 9/16" COPPER SHIELD PLATE
 C
 1698 0 675 -664 624 -146
 C
 1699 1 -7.9 664 -600 627 -626 \$ 9/16" SS SHIELD PLATE
 1700 1 -7.9 664 -600 626 -625 \$ " " " "
 1701 1 -7.9 664 -600 625 -624 \$ " " " "
 1702 4 -8.96 675 -664 627 -626 \$ " Cu " "
 1703 4 -8.96 675 -664 626 -625 \$ " " " "
 1704 4 -8.96 675 -664 625 -624 \$ " " " "
 C
 1705 8 -7.84 676 -677 -760 \$ ELEVATOR FLOOR
 1706 8 -7.84 676 -677 760 -761
 1707 8 -7.84 676 -677 761 -748
 1708 8 -7.84 676 -677 748 -749
 1709 8 -7.84 676 -677 749 -750
 1710 8 -7.84 676 -677 750 -751
 1711 8 -7.84 676 -677 751 -752
 1712 8 -7.84 676 -677 752 -753
 1713 8 -7.84 676 -677 753 -754

1714	8	-7.84	676	-677	754	-755						
1715	8	-7.84	676	-677	755	-756						
1716	8	-7.84	676	-677	756	-762						
1717	8	-7.84	676	-677	762	-757						
1718	8	-7.84	676	-677	757	-758						
1719	8	-7.84	676	-677	758	-759						
1720	8	-7.84	676	-677	759	-649						
1721	8	-7.84	676	-677	649	-648						
1722	8	-7.84	676	-677	648	-647						
1723	8	-7.84	676	-677	647	-646						
1724	8	-7.84	676	-677	646	-645						
1725	8	-7.84	676	-677	645	-644						
1726	8	-7.84	676	-677	644	-643						
1727	8	-7.84	676	-677	643	-642						
1728	8	-7.84	676	-677	642	-641						
1729	8	-7.84	676	-677	641	-640						
1730	8	-7.84	676	-677	640	-639						
1731	8	-7.84	676	-677	639	-638						
1732	8	-7.84	676	-677	638	-637						
1733	8	-7.84	676	-677	637	-636						
1734	8	-7.84	676	-677	636	-635						
1735	8	-7.84	676	-677	635	-634						
1736	8	-7.84	676	-677	634	-633						
1737	8	-7.84	676	-677	633	-632						
1738	8	-7.84	676	-677	632	-631						
1739	8	-7.84	676	-677	631	-630						
1740	8	-7.84	676	-677	630	-629						
1741	8	-7.84	676	-677	629	-628						
1742	8	-7.84	676	-677	628	-627						
1743	8	-7.84	676	-677	627	-626						
1744	8	-7.84	676	-677	626	-625						
1745	8	-7.84	676	-677	625	-624						
1746	8	-7.84	676	-677	624	-623						
1747	8	-7.84	676	-677	623	-622						
1748	8	-7.84	676	-677	622	-621						
1749	8	-7.84	676	-677	621	-620						
1750	8	-7.84	676	-677	620	-619						
1751	8	-7.84	676	-677	619	-618						
1752	8	-7.84	676	-677	618	-617						
1753	8	-7.84	676	-677	617	-616						
1754	8	-7.84	676	-677	616	-615						
1755	8	-7.84	676	-677	615	-614						
1756	8	-7.84	676	-677	614	-613						
1757	8	-7.84	676	-677	613	-612						
1758	8	-7.84	676	-677	612	-611						
1759	8	-7.84	676	-677	611	-610						
1760	8	-7.84	676	-677	610	-609						
1761	8	-7.84	676	-677	609	-608						
1762	8	-7.84	676	-677	608	-607						
1763	8	-7.84	676	-677	607	-606						
1764	8	-7.84	676	-677	606	-605						
1765	8	-7.84	676	-677	605	-604						
1766	8	-7.84	676	-677	604	-603						
1767	8	-7.84	676	-677	603	-602						
1768	8	-7.84	676	-677	602	-601						
1769	8	-7.84	676	-677	601	-146						
1770	8	-7.84	676	-677	146	-147						
												\$ ELEVATOR FLOOR
												C
1771	0	430	-784	-147	#2287	#2288	#2289	#2290	#2291	#2292	&	
					#2293	#2294						
												C
												\$ VOID B/W BOTTOM OF PIG AND ELEVATOR FLOOR
												C
												C
1772	1	-7.9	679	-495	681	-682	-680	683	#1436	#1446	#1286	#1204 \$ SIDE PLATES
1773	1	-7.9	681	-682	495	-494	-680	683	#1437	#1447	#1287	#1216 \$ ON PIG
1774	1	-7.9	681	-682	494	-493	-680	683	#1438	#1448	#1288	#1228
1775	1	-7.9	681	-682	493	-492	-680	683	#1439	#1449	#1289	#1240
1776	1	-7.9	681	-682	492	-491	-680	683	#1440	#1450	#1252	
1777	1	-7.9	681	-682	491	-490	-680	683	#1441	#1451	#1264	
1778	1	-7.9	681	-682	490	-489	-680	683	#1442	#1452	#1276	
1779	1	-7.9	681	-682	489	-488	-680	683	#1385	#1337	#1149	
1780	1	-7.9	681	-682	488	-487	-680	683	#1386	#1338	#1150	

1781	1	-7.9	681	-682	487	-486	-680	683	#1387	#1339	#1151
1782	1	-7.9	681	-682	486	-485	-680	683	#1388	#1340	#1152
1783	1	-7.9	681	-682	485	-484	-680	683	#1389	#1341	#1153
1784	1	-7.9	681	-682	484	-483	-680	683	#1390	#1342	#1154
1785	1	-7.9	681	-682	483	-482	-680	683	#1391	#1343	#1155
1786	1	-7.9	681	-682	482	-471	-680	683	#1392	#1344	#1156
1787	1	-7.9	681	-682	471	-472	-680	683	#1402	#1354	#1129
1788	1	-7.9	681	-682	472	-473	-680	683	#1403	#1355	#1130
1789	1	-7.9	681	-682	473	-474	-680	683	#1404	#1356	#1131
1790	1	-7.9	681	-682	474	-475	-680	683	#1405	#1357	#1132
1791	1	-7.9	681	-682	475	-476	-680	683	#1406	#1358	#1133
1792	1	-7.9	681	-682	476	-477	-680	683	#1407	#1359	#1134
1793	1	-7.9	681	-682	477	-478	-680	683	#1408	#1360	#1135
1794	1	-7.9	681	-682	478	-479	-680	683	#1409	#1361	#1136
1795	1	-7.9	681	-682	479	-480	-680	683	#1410	#1362	#1137
1796	1	-7.9	681	-682	480	-481	-680	683	#1411	#1363	#1138
1797	1	-7.9	681	-682	481	-434	-680	683	#1412	#1364	#1139
1798	1	-7.9	681	-682	434	-435	-680	683	#1413	#1365	#1063
1799	1	-7.9	681	-682	435	-436	-680	683	#1414	#1366	#1064
1800	1	-7.9	681	-682	436	-437	-680	683	#1415	#1367	#1065
1801	1	-7.9	681	-682	437	-438	-680	683	#1416	#1368	#1066
1802	1	-7.9	681	-682	438	-439	-680	683	#1417	#1369	#1067
1803	1	-7.9	681	-682	439	-440	-680	683	#1418	#1370	#1068
1804	1	-7.9	681	-682	440	-441	-680	683	#1419	#1371	#1069
1805	1	-7.9	681	-682	441	-442	-680	683	#1420	#1372	#1070
1806	1	-7.9	681	-682	442	-443	-680	683	#1421	#1373	#1071
1807	1	-7.9	681	-682	443	-444	-680	683	#1422	#1374	#1072
1808	1	-7.9	681	-682	444	-445	-680	683	#1423	#1375	#1073
1809	1	-7.9	681	-682	445	-18	-680	683	#1424	#1376	#1074
1810	1	-7.9	681	-682	18	-460	-680	683	#1425	#1377	#1075
1811	1	-7.9	681	-682	460	-446	-680	683	#1426	#1378	#1076
1812	1	-7.9	681	-682	446	-447	-680	683	#1427	#1379	#1077
1813	1	-7.9	681	-682	447	-448	-680	683	#1428	#1380	#1078
1814	1	-7.9	681	-682	448	-449	-680	683	#1429	#1381	#1079
1815	1	-7.9	681	-682	449	-428	-680	683	#1430	#1382	#1080
1816	1	-7.9	681	-682	428	-429	-680	683	#1431	#1383	#1081
1817	1	-7.9	681	-682	429	-430	-680	683	#1432	#1384	#1082
C											
1818	0	498	-679	509	-147						
C											
1819	0	679	-430	-680	683	-681	-147	\$	VOIDS AROUND PIG		
C											
1820	0	679	-430	-680	683	682	-147				
C											
1821	0	679	-430	-685	684	-681	-147	#2289			
C											
1822	0	679	-430	-685	684	682	-147	#2291			
C											
1823	0	679	-430	-683	685	509	-147				
C											
C 1823	0	679	-430	-683	685	509	-147				
C											
C 1824	0	679	-430	681	-682	684	509				
C											
1824	0	679	-471	-684	-147						
1825	0	471	-434	-684	-147						
1826	0	434	-430	-684	-21	#2287	#2289	#2291			
C											
1827	1	-7.9	679	-495	681	-682	-685	684	#1436	#1446	#1286 #1204 \$ SIDE PLATES ON PIG
1828	1	-7.9	681	-682	495	-494	-685	684	#1437	#1447	#1287 #1216
1829	1	-7.9	681	-682	494	-493	-685	684	#1438	#1448	#1288 #1228
1830	1	-7.9	681	-682	493	-492	-685	684	#1439	#1449	#1289 #1240
1831	1	-7.9	681	-682	492	-491	-685	684	#1440	#1450	#1252
1832	1	-7.9	681	-682	491	-490	-685	684	#1441	#1451	#1264
1833	1	-7.9	681	-682	490	-489	-685	684	#1442	#1452	#1276
1834	1	-7.9	681	-682	489	-488	-685	684	#1385	#1337	#1149
1835	1	-7.9	681	-682	488	-487	-685	684	#1386	#1338	#1150
1836	1	-7.9	681	-682	487	-486	-685	684	#1387	#1339	#1151
1837	1	-7.9	681	-682	486	-485	-685	684	#1388	#1340	#1152
1838	1	-7.9	681	-682	485	-484	-685	684	#1389	#1341	#1153
1839	1	-7.9	681	-682	484	-483	-685	684	#1390	#1342	#1154

1840 1 -7.9 681 -682 483 -482 -685 684 #1391 #1343 #1155
1841 1 -7.9 681 -682 482 -471 -685 684 #1392 #1344 #1156
1842 1 -7.9 681 -682 471 -472 -685 684 #1402 #1354 #1129
1843 1 -7.9 681 -682 472 -473 -685 684 #1403 #1355 #1130
1844 1 -7.9 681 -682 473 -474 -685 684 #1404 #1356 #1131
1845 1 -7.9 681 -682 474 -475 -685 684 #1405 #1357 #1132
1846 1 -7.9 681 -682 475 -476 -685 684 #1406 #1358 #1133
1847 1 -7.9 681 -682 476 -477 -685 684 #1407 #1359 #1134
1848 1 -7.9 681 -682 477 -478 -685 684 #1408 #1360 #1135
1849 1 -7.9 681 -682 478 -479 -685 684 #1409 #1361 #1136
1850 1 -7.9 681 -682 479 -480 -685 684 #1410 #1362 #1137
1851 1 -7.9 681 -682 480 -481 -685 684 #1411 #1363 #1138
1852 1 -7.9 681 -682 481 -434 -685 684 #1412 #1364 #1139
1853 1 -7.9 681 -682 434 -435 -685 684 #1413 #1365 #1063
1854 1 -7.9 681 -682 435 -436 -685 684 #1414 #1366 #1064
1855 1 -7.9 681 -682 436 -437 -685 684 #1415 #1367 #1065
1856 1 -7.9 681 -682 437 -438 -685 684 #1416 #1368 #1066
1857 1 -7.9 681 -682 438 -439 -685 684 #1417 #1369 #1067
1858 1 -7.9 681 -682 439 -440 -685 684 #1418 #1370 #1068
1859 1 -7.9 681 -682 440 -441 -685 684 #1419 #1371 #1069
1860 1 -7.9 681 -682 441 -442 -685 684 #1420 #1372 #1070
1861 1 -7.9 681 -682 442 -443 -685 684 #1421 #1373 #1071
1862 1 -7.9 681 -682 443 -444 -685 684 #1422 #1374 #1072
1863 1 -7.9 681 -682 444 -445 -685 684 #1423 #1375 #1073
1864 1 -7.9 681 -682 445 -18 -685 684 #1424 #1376 #1074
1865 1 -7.9 681 -682 18 -460 -685 684 #1425 #1377 #1075
1866 1 -7.9 681 -682 460 -446 -685 684 #1426 #1378 #1076
1867 1 -7.9 681 -682 446 -447 -685 684 #1427 #1379 #1077
1868 1 -7.9 681 -682 447 -448 -685 684 #1428 #1380 #1078
1869 1 -7.9 681 -682 448 -449 -685 684 #1429 #1381 #1079
1870 1 -7.9 681 -682 449 -428 -685 684 #1430 #1382 #1080
1871 1 -7.9 681 -682 428 -429 -685 684 #1431 #1383 #1081
1872 1 -7.9 681 -682 429 -430 -685 684 #1432 #1384 #1082
C
1873 0 434 -430 21 -147 680
1874 0 434 -430 21 -147 -684
C
1875 9 -0.915 686 -504 -454 453 \$ 6 INCHES POLY ON TOP OF Pb
1876 9 -0.915 686 -504 -453 452
1877 9 -0.915 686 -504 -452 451
1878 9 -0.915 686 -504 -451 692
C 1879 9 -0.915 686 -504 -450 692
C
C 1880 9 -0.915 686 -504 -137 692
C 1881 0 686 -504 -692 \$ CTR HOLE THRU POLY
C
1882 9 -0.915 687 -686 -454 453
1883 9 -0.915 687 -686 -453 452
1884 9 -0.915 687 -686 -452 451
1885 9 -0.915 687 -686 -451 692
C 1886 9 -0.915 687 -686 -450 692
C
C 1887 9 -0.915 687 -686 -137 692
C 1888 0 687 -686 -692 \$ CTR HOLE THRU POLY
C
1889 9 -0.915 688 -687 -454 453
1890 9 -0.915 688 -687 -453 452
1891 9 -0.915 688 -687 -452 451
1892 9 -0.915 688 -687 -451 692
C 1893 9 -0.915 688 -687 -450 692
C
C 1894 9 -0.915 688 -687 -137 692
C 1895 0 688 -687 -692 \$ CTR HOLE THRU POLY
C
1896 9 -0.915 689 -688 -454 453
1897 9 -0.915 689 -688 -453 452
1898 9 -0.915 689 -688 -452 451
1899 9 -0.915 689 -688 -451 692
C 1900 9 -0.915 689 -688 -450 692
C
C 1901 9 -0.915 689 -688 -137 692
C 1902 0 689 -688 -692 \$ CTR HOLE THRU POLY

C
 1903 9 -0.915 690 -689 -454 453
 1904 9 -0.915 690 -689 -453 452
 1905 9 -0.915 690 -689 -452 451
 1906 9 -0.915 690 -689 -451 692
 C 1907 9 -0.915 690 -689 -450 692
 C
 C 1908 9 -0.915 690 -689 -137 692
 C 1909 0 690 -689 -692 \$ CTR HOLE THRU POLY
 C
 1910 9 -0.915 691 -690 -454 453
 1911 9 -0.915 691 -690 -453 452
 1912 9 -0.915 691 -690 -452 451
 1913 9 -0.915 691 -690 -451 692
 C 1914 9 -0.915 691 -690 -450 692
 C
 C 1915 9 -0.915 691 -690 -137 692
 C 1916 0 691 -690 -692 \$ CTR HOLE THRU POLY; END OF 6 INCHES POLY ON TOP OF
 Pb
 C
 1917 0 695 -504 433 -147 \$ Void b/w poly and stack
 C
 1918 9 -0.915 693 -691 -454 453 \$ 3 FOOT STACK OF POLY
 1919 9 -0.915 693 -691 -453 452
 1920 9 -0.915 693 -691 -452 451
 1921 9 -0.915 693 -691 -451 692
 C 1922 9 -0.915 693 -691 -450 692
 C 1923 9 -0.915 693 -691 -137 692
 1924 9 -0.915 694 -693 -454 453
 1925 9 -0.915 694 -693 -453 452
 1926 9 -0.915 694 -693 -452 451
 1927 9 -0.915 694 -693 -451 692
 C 1928 9 -0.915 694 -693 -450 692
 C 1929 9 -0.915 694 -693 -137 692
 1930 9 -0.915 695 -694 -454 453
 1931 9 -0.915 695 -694 -453 452
 1932 9 -0.915 695 -694 -452 451
 1933 9 -0.915 695 -694 -451 692
 C 1934 9 -0.915 695 -694 -450 692
 C 1935 9 -0.915 695 -694 -137 692
 1936 9 -0.915 696 -695 -454 453
 1937 9 -0.915 696 -695 -453 452
 1938 9 -0.915 696 -695 -452 451
 1939 9 -0.915 696 -695 -451 692
 C 1940 9 -0.915 696 -695 -450 692
 C 1941 9 -0.915 696 -695 -137 692
 1942 9 -0.915 697 -696 -454 453
 1943 9 -0.915 697 -696 -453 452
 1944 9 -0.915 697 -696 -452 451
 1945 9 -0.915 697 -696 -451 692
 C 1946 9 -0.915 697 -696 -450 692
 C 1947 9 -0.915 697 -696 -137 692
 C
 1948 9 -0.915 698 -697 -454 453
 1949 9 -0.915 698 -747 -453 692
 1950 9 -0.915 747 -697 -453 692
 C
 C 1951 9 -0.915 698 -697 -451 692
 C 1952 9 -0.915 698 -697 -450 692
 C 1953 9 -0.915 698 -697 -137 692
 C
 1954 9 -0.915 699 -698 -454 453
 1955 9 -0.915 699 -746 -453 692
 1956 9 -0.915 746 -698 -453 692
 C
 C 1957 9 -0.915 699 -698 -451 692
 C 1958 9 -0.915 699 -698 -450 692
 C 1959 9 -0.915 699 -698 -137 692
 C
 1960 9 -0.915 700 -699 -454 453
 1961 9 -0.915 700 -745 -453 692
 1962 9 -0.915 745 -699 -453 692

C
C 1963 9 -0.915 700 -699 -451 692
C 1964 9 -0.915 700 -699 -450 692
C 1965 9 -0.915 700 -699 -137 692
C
1966 9 -0.915 701 -700 -454 453
1967 9 -0.915 701 -744 -453 692
1968 9 -0.915 744 -700 -453 692
C
C 1969 9 -0.915 701 -700 -451 692
C 1970 9 -0.915 701 -700 -450 692
C 1971 9 -0.915 701 -700 -137 692
C
1972 9 -0.915 702 -701 -454 453
1973 9 -0.915 702 -743 -453 692
1974 9 -0.915 743 -701 -453 692
C
C 1975 9 -0.915 702 -701 -451 692
C 1976 9 -0.915 702 -701 -450 692
C 1977 9 -0.915 702 -701 -137 692
C
1978 9 -0.915 703 -702 -454 453
1979 9 -0.915 703 -742 -453 692
1980 9 -0.915 742 -702 -453 692
C
C 1981 9 -0.915 703 -702 -451 692
C 1982 9 -0.915 703 -702 -450 692
C 1983 9 -0.915 703 -702 -137 692
C
1984 9 -0.915 704 -703 -454 453
1985 9 -0.915 704 -741 -453 692
1986 9 -0.915 741 -703 -453 692
C
C 1987 9 -0.915 704 -703 -451 692
C 1988 9 -0.915 704 -703 -450 692
C 1989 9 -0.915 704 -703 -137 692
C
1990 9 -0.915 705 -704 -454 453
1991 9 -0.915 705 -740 -453 692
1992 9 -0.915 740 -704 -453 692
C
C 1993 9 -0.915 705 -704 -451 692
C 1994 9 -0.915 705 -704 -450 692
C 1995 9 -0.915 705 -704 -137 692
C
1996 9 -0.915 706 -705 -454 453
1997 9 -0.915 706 -739 -453 692
1998 9 -0.915 739 -705 -453 692
C
C 1999 9 -0.915 706 -705 -451 692
C 2000 9 -0.915 706 -705 -450 692
C 2001 9 -0.915 706 -705 -137 692
C
2002 9 -0.915 707 -706 -454 453
2003 9 -0.915 707 -738 -453 692
2004 9 -0.915 738 -706 -453 692
C
C 2005 9 -0.915 707 -706 -451 692
C 2006 9 -0.915 707 -706 -450 692
C 2007 9 -0.915 707 -706 -137 692
C
2008 9 -0.915 708 -707 -454 453
2009 9 -0.915 708 -737 -453 692
2010 9 -0.915 737 -707 -453 692
C
C 2011 9 -0.915 708 -707 -451 692
C 2012 9 -0.915 708 -707 -450 692
C 2013 9 -0.915 708 -707 -137 692
C
2014 9 -0.915 709 -708 -454 453
2015 9 -0.915 709 -736 -453 692
2016 9 -0.915 736 -708 -453 692

C
 C 2017 9 -0.915 709 -708 -451 692
 C 2018 9 -0.915 709 -708 -450 692
 C 2019 9 -0.915 709 -708 -137 692
 C
 2020 9 -0.915 710 -709 -454 453
 2021 9 -0.915 710 -723 -453 692
 2022 9 -0.915 723 -709 -453 692
 C
 C 2023 9 -0.915 710 -709 -451 692
 C 2024 9 -0.915 710 -709 -450 692
 C 2025 9 -0.915 710 -709 -137 692
 C
 2026 9 -0.915 711 -710 -454 453
 2027 9 -0.915 711 -724 -453 692
 2028 9 -0.915 724 -710 -453 692
 C
 C 2029 9 -0.915 711 -710 -451 692
 C 2030 9 -0.915 711 -710 -450 692
 C 2031 9 -0.915 711 -710 -137 692
 C
 2032 9 -0.915 712 -711 -454 453
 2033 9 -0.915 712 -725 -453 692
 2034 9 -0.915 725 -711 -453 692
 C
 C 2035 9 -0.915 712 -711 -451 692
 C 2036 9 -0.915 712 -711 -450 692
 C 2037 9 -0.915 712 -711 -137 692
 C
 2038 9 -0.915 713 -712 -454 453
 2039 9 -0.915 713 -726 -453 692
 2040 9 -0.915 726 -712 -453 692
 C
 C 2041 9 -0.915 713 -712 -451 692
 C 2042 9 -0.915 713 -712 -450 692
 C 2043 9 -0.915 713 -712 -137 692
 C
 2044 9 -0.915 714 -713 -454 453
 2045 9 -0.915 714 -727 -453 692
 2046 9 -0.915 727 -713 -453 692
 C
 C 2047 9 -0.915 714 -713 -451 692
 C 2048 9 -0.915 714 -713 -450 692
 C 2049 9 -0.915 714 -713 -137 692
 C
 2050 9 -0.915 715 -714 -454 453
 2051 9 -0.915 715 -728 -453 692
 2052 9 -0.915 728 -714 -453 692
 C
 C 2053 9 -0.915 715 -714 -451 692
 C 2054 9 -0.915 715 -714 -450 692
 C 2055 9 -0.915 715 -714 -137 692
 C
 2056 9 -0.915 716 -715 -454 453
 2057 9 -0.915 716 -729 -453 692
 2058 9 -0.915 729 -715 -453 692
 C
 C 2059 9 -0.915 716 -715 -451 692
 C 2060 9 -0.915 716 -715 -450 692
 C 2061 9 -0.915 716 -715 -137 692
 C
 2062 9 -0.915 717 -716 -454 453
 2063 9 -0.915 717 -730 -453 692
 2064 9 -0.915 730 -716 -453 692
 C
 C 2065 9 -0.915 717 -716 -451 692
 C 2066 9 -0.915 717 -716 -450 692
 C 2067 9 -0.915 717 -716 -137 692
 C
 2068 9 -0.915 718 -717 -454 453
 2069 9 -0.915 718 -731 -453 692
 2070 9 -0.915 731 -717 -453 692

C
 C 2071 9 -0.915 718 -717 -451 692
 C 2072 9 -0.915 718 -717 -450 692
 C 2073 9 -0.915 718 -717 -137 692
 C
 2074 9 -0.915 719 -718 -454 453
 2075 9 -0.915 719 -732 -453 692
 2076 9 -0.915 732 -718 -453 692
 C
 C 2077 9 -0.915 719 -718 -451 692
 C 2078 9 -0.915 719 -718 -450 692
 C 2079 9 -0.915 719 -718 -137 692
 C
 2080 9 -0.915 720 -719 -454 453
 2081 9 -0.915 720 -733 -453 692
 2082 9 -0.915 733 -719 -453 692
 C
 C 2083 9 -0.915 720 -719 -451 692
 C 2084 9 -0.915 720 -719 -450 692
 C 2085 9 -0.915 720 -719 -137 692
 C
 2086 9 -0.915 734 -720 -454 452
 2087 9 -0.915 734 -720 -451 692
 2088 9 -0.915 734 -720 -452 451
 C
 C 2089 9 -0.915 721 -720 -451 692
 C 2090 9 -0.915 721 -720 -450 692
 C 2091 9 -0.915 721 -720 -137 692
 C
 C 2092 9 -0.915 722 -721 -454 453
 C 2093 9 -0.915 722 -735 -453 692
 C 2094 9 -0.915 735 -721 -453 692
 C
 C 2095 9 -0.915 722 -721 -451 692
 C 2096 9 -0.915 722 -721 -450 692
 C 2097 9 -0.915 722 -721 -137 692
 C
 2098 0 734 -504 -692 \$ VOID INSIDE POLY
 C
 2099 9 -0.915 706 -739 454 -455 \$ 4th SECTION POLY
 2100 9 -0.915 707 -706 454 -455
 2101 9 -0.915 708 -707 454 -455
 2102 9 -0.915 709 -708 454 -455
 2103 9 -0.915 710 -709 454 -455
 2104 9 -0.915 711 -710 454 -455
 2105 9 -0.915 712 -711 454 -455
 2106 9 -0.915 713 -712 454 -455
 2107 9 -0.915 714 -713 454 -455
 2108 9 -0.915 715 -714 454 -455
 2109 9 -0.915 716 -715 454 -455
 C
 2110 0 716 -739 455 -147
 C
 2111 1 -7.9 -799 #1771 \$ 16" DIA SS PLATE
 C
 C 2112 1 -7.9 784 -785 760 -761 \$ @ BOTTOM OF YOKE
 C 2113 1 -7.9 784 -785 761 -748 \$ (WHERE YOKE SWIVELS)
 C 2114 1 -7.9 784 -785 748 -749
 C 2115 1 -7.9 784 -785 749 -750
 C 2116 1 -7.9 784 -785 750 -751
 C 2117 1 -7.9 784 -785 751 -752
 C 2118 1 -7.9 784 -785 752 -753
 C 2119 1 -7.9 784 -785 753 -754
 C
 2120 0 784 -785 799 -147 #1826 #1874 #2287 #2288 #2286
 C
 C 2121 8 -7.84 785 -786 -760 \$ 1/2" PLATE OF PIG
 C 2122 8 -7.84 785 -786 760 -761 \$ CHASSIS
 C 2123 8 -7.84 785 -786 761 -748
 C 2124 8 -7.84 785 -786 748 -749
 C 2125 8 -7.84 785 -786 749 -750
 C 2126 8 -7.84 785 -786 750 -751

C 2127	8	-7.84	785	-786	751	-752	
C 2128	8	-7.84	785	-786	752	-753	
C 2129	8	-7.84	785	-786	753	-754	
C 2130	8	-7.84	785	-786	754	-755	
C 2131	8	-7.84	785	-786	755	-756	
C 2132	8	-7.84	785	-786	756	-762	
C 2133	8	-7.84	785	-786	762	-757	
C 2134	8	-7.84	785	-786	757	-758	
C 2135	8	-7.84	785	-786	758	-759	
C 2136	8	-7.84	785	-786	759	-649	
C 2137	8	-7.84	785	-786	649	-648	
C 2138	8	-7.84	785	-786	648	-647	
C 2139	8	-7.84	785	-786	647	-646	
C 2140	8	-7.84	785	-786	646	-645	
C 2141	8	-7.84	785	-786	645	-644	
C 2142	8	-7.84	785	-786	644	-643	
C 2143	8	-7.84	785	-786	643	-642	
C							
2144	0	785	-786	792	-147	#2288 #2286 #2287	
2145	0	786	-676	-147	#1874 #2286 \$	#2144	
C							
C 2146	8	-7.84	785	-786	642	-641	
C							
2147	9	-0.915	500	-499	780	-781	\$ BEGINNING OF 30.5" DIA
2148	9	-0.915	500	-499	508	-780	\$ BORATED POLY PIECE (RIGHT
2149	9	-0.915	500	-499	433	-508	\$ NOW, IT'S JUST POLY)
2150	9	-0.915	500	-499	432	-433	\$ AROUND Pb, RESTING ON TOP
2151	9	-0.915	500	-499	458	-432	\$ OF PIG
2152	9	-0.915	500	-499	457	-458	
2153	9	-0.915	500	-499	456	-457	
2154	9	-0.915	500	-499	455	-456	
2155	9	-0.915	500	-499	454	-455	
2156	9	-0.915	501	-500	780	-781	
2157	9	-0.915	501	-500	508	-780	
2158	9	-0.915	501	-500	433	-508	
2159	9	-0.915	501	-500	432	-433	
2160	9	-0.915	501	-500	458	-432	
2161	9	-0.915	501	-500	457	-458	
2162	9	-0.915	501	-500	456	-457	
2163	9	-0.915	501	-500	455	-456	
2164	9	-0.915	501	-500	454	-455	
2165	9	-0.915	502	-501	780	-781	
2166	9	-0.915	502	-501	508	-780	
2167	9	-0.915	502	-501	433	-508	
2168	9	-0.915	502	-501	432	-433	
2169	9	-0.915	502	-501	458	-432	
2170	9	-0.915	502	-501	457	-458	
2171	9	-0.915	502	-501	456	-457	
2172	9	-0.915	502	-501	455	-456	
2173	9	-0.915	502	-501	454	-455	
2174	9	-0.915	503	-502	780	-781	
2175	9	-0.915	503	-502	508	-780	
2176	9	-0.915	503	-502	433	-508	
2177	9	-0.915	503	-502	432	-433	
2178	9	-0.915	503	-502	458	-432	
2179	9	-0.915	503	-502	457	-458	
2180	9	-0.915	503	-502	456	-457	
2181	9	-0.915	503	-502	455	-456	
2182	9	-0.915	503	-502	454	-455	
2183	9	-0.915	504	-503	780	-781	
2184	9	-0.915	504	-503	508	-780	
2185	9	-0.915	504	-503	433	-508	
2186	9	-0.915	504	-503	432	-433	
2187	9	-0.915	504	-503	458	-432	
2188	9	-0.915	504	-503	457	-458	
2189	9	-0.915	504	-503	456	-457	
2190	9	-0.915	504	-503	455	-456	
2191	9	-0.915	504	-503	454	-455	
C							
2192	9	-0.915	504	-503	781	-782	
2193	9	-0.915	503	-502	781	-782	
2194	9	-0.915	502	-501	781	-782	

2195	9	-0.915	501	-500	781	-782	
2196	9	-0.915	500	-499	781	-782	\$ END OF 30.5" DIA POLY
C							
2197	9	-0.915	686	-504	432	-433	\$ BEGINNING OF 2, 2FT DIA
2198	9	-0.915	686	-504	458	-432	\$ PIECES OF POLY ON TOP
2199	9	-0.915	686	-504	457	-458	\$ OF Pb
2200	9	-0.915	686	-504	456	-457	
2201	9	-0.915	686	-504	455	-456	
2202	9	-0.915	686	-504	454	-455	
2203	9	-0.915	687	-686	432	-433	
2204	9	-0.915	687	-686	458	-432	
2205	9	-0.915	687	-686	457	-458	
2206	9	-0.915	687	-686	456	-457	
2207	9	-0.915	687	-686	455	-456	
2208	9	-0.915	687	-686	454	-455	
2209	9	-0.915	688	-687	432	-433	
2210	9	-0.915	688	-687	458	-432	
2211	9	-0.915	688	-687	457	-458	
2212	9	-0.915	688	-687	456	-457	
2213	9	-0.915	688	-687	455	-456	
2214	9	-0.915	688	-687	454	-455	
2215	9	-0.915	689	-688	432	-433	
2216	9	-0.915	689	-688	458	-432	
2217	9	-0.915	689	-688	457	-458	
2218	9	-0.915	689	-688	456	-457	
2219	9	-0.915	689	-688	455	-456	
2220	9	-0.915	689	-688	454	-455	
2221	9	-0.915	690	-689	432	-433	
2222	9	-0.915	690	-689	458	-432	
2223	9	-0.915	690	-689	457	-458	
2224	9	-0.915	690	-689	456	-457	
2225	9	-0.915	690	-689	455	-456	
2226	9	-0.915	690	-689	454	-455	
2227	9	-0.915	691	-690	432	-433	
2228	9	-0.915	691	-690	458	-432	
2229	9	-0.915	691	-690	457	-458	
2230	9	-0.915	691	-690	456	-457	
2231	9	-0.915	691	-690	455	-456	
2232	9	-0.915	691	-690	454	-455	
2233	9	-0.915	693	-691	432	-433	
2234	9	-0.915	693	-691	458	-432	
2235	9	-0.915	693	-691	457	-458	
2236	9	-0.915	693	-691	456	-457	
2237	9	-0.915	693	-691	455	-456	
2238	9	-0.915	693	-691	454	-455	
2239	9	-0.915	694	-693	432	-433	
2240	9	-0.915	694	-693	458	-432	
2241	9	-0.915	694	-693	457	-458	
2242	9	-0.915	694	-693	456	-457	
2243	9	-0.915	694	-693	455	-456	
2244	9	-0.915	694	-693	454	-455	
2245	9	-0.915	695	-694	432	-433	
2246	9	-0.915	695	-694	458	-432	
2247	9	-0.915	695	-694	457	-458	
2248	9	-0.915	695	-694	456	-457	
2249	9	-0.915	695	-694	455	-456	
2250	9	-0.915	695	-694	454	-455	
C							
2251	0	734	-716	454	-147		
C							
2252	9	-0.915	696	-695	456	-457	
2253	9	-0.915	696	-695	455	-456	
2254	9	-0.915	696	-695	454	-455	
2255	9	-0.915	697	-696	456	-457	
2256	9	-0.915	697	-696	455	-456	
2257	9	-0.915	697	-696	454	-455	
2258	9	-0.915	698	-697	456	-457	
2259	9	-0.915	698	-697	455	-456	
2260	9	-0.915	698	-697	454	-455	
2261	9	-0.915	699	-698	456	-457	
2262	9	-0.915	699	-698	455	-456	
2263	9	-0.915	699	-698	454	-455	

```

2264 9 -0.915 700 -699 456 -457
2265 9 -0.915 700 -699 455 -456
2266 9 -0.915 700 -699 454 -455
2267 9 -0.915 701 -700 456 -457
2268 9 -0.915 701 -700 455 -456
2269 9 -0.915 701 -700 454 -455
2270 9 -0.915 702 -701 456 -457
2271 9 -0.915 702 -701 455 -456
2272 9 -0.915 702 -701 454 -455
2273 9 -0.915 703 -702 456 -457
2274 9 -0.915 703 -702 455 -456
2275 9 -0.915 703 -702 454 -455
2276 9 -0.915 704 -703 456 -457
2277 9 -0.915 704 -703 455 -456
2278 9 -0.915 704 -703 454 -455
2279 9 -0.915 705 -704 456 -457
2280 9 -0.915 705 -704 455 -456
2281 9 -0.915 705 -704 454 -455
2282 9 -0.915 739 -705 456 -457
2283 9 -0.915 739 -705 455 -456
2284 9 -0.915 739 -705 454 -455
C
2285 0 739 -695 457 -147
C
2286 8 -7.84 -792 $ #2120
C
2287 8 -7.84 -793 #2286 #2145 #2290
C
2288 8 -7.84 -794 #2286 #2145 #2292
C
2289 8 -7.84 -795 #2290
C
2290 8 -7.84 -796
C
2291 8 -7.84 -797 #2292
C
2292 8 -7.84 -798
C
2293 8 -7.84 -800 801
C
2294 0 -801
C
2295 1 -7.9 -1 900 23 -22 $ INNER MITL EXTENSION
2296 1 -7.9 -900 901 23 -22
2297 1 -7.9 -901 902 23 -22
2298 1 -7.9 -902 903 23 -22
2299 1 -7.9 -903 904 23 -22
2300 1 -7.9 -904 905 23 -22
C 2301 0 144 -146 -1 909
2302 0 -928 26 -147
2303 1 -7.9 -1 900 -144 143 $ OUTER MITL EXTENSION
2304 1 -7.9 -900 901 -144 143
2305 1 -7.9 -901 902 -144 143
2306 1 -7.9 -902 903 -144 143
2307 1 -7.9 -903 904 -144 143
2308 1 -7.9 -904 905 -144 143
2309 1 -7.9 -905 906 -144 143
2310 1 -7.9 -906 907 -144 143
2311 1 -7.9 -907 908 -144 143
C
2312 1 -7.9 -1 900 -147 146 $ EXTENSION OF STACK
2313 1 -7.9 -900 901 -147 146
2314 1 -7.9 -901 902 -147 146
2315 1 -7.9 -902 903 -147 146
2316 1 -7.9 -903 904 -147 146
2317 1 -7.9 -904 905 -147 146
2318 1 -7.9 -905 906 -147 146
2319 1 -7.9 -906 907 -147 146
2320 1 -7.9 -907 908 -147 146
C
2321 1 -7.9 -909 908 144 -752
2322 1 -7.9 -909 908 752 -753

```

2323	1	-7.9	-909	908	753	-754
2324	1	-7.9	-909	908	754	-755
2325	1	-7.9	-909	908	755	-756
2326	1	-7.9	-909	908	756	-757
2327	1	-7.9	-909	908	757	-758
2328	1	-7.9	-909	908	758	-759
2329	1	-7.9	-909	908	759	-649
2330	1	-7.9	-909	908	649	-648
2331	1	-7.9	-909	908	648	-647
2332	1	-7.9	-909	908	647	-646
2333	1	-7.9	-909	908	646	-645
2334	1	-7.9	-909	908	645	-644
2335	1	-7.9	-909	908	644	-643
2336	1	-7.9	-909	908	643	-642
2337	1	-7.9	-909	908	642	-641
2338	1	-7.9	-909	908	641	-640
2339	1	-7.9	-909	908	640	-639
2340	1	-7.9	-909	908	639	-638
2341	1	-7.9	-909	908	638	-637
2342	1	-7.9	-909	908	637	-636
2343	1	-7.9	-909	908	636	-635
2344	1	-7.9	-909	908	635	-634
2345	1	-7.9	-909	908	634	-633
2346	1	-7.9	-909	908	633	-632
2347	1	-7.9	-909	908	632	-631
2348	1	-7.9	-909	908	631	-630
2349	1	-7.9	-909	908	630	-629
2350	1	-7.9	-909	908	629	-628
2351	1	-7.9	-909	908	628	-627
2352	1	-7.9	-909	908	627	-626
2353	1	-7.9	-909	908	626	-625
2354	1	-7.9	-909	908	625	-624
2355	1	-7.9	-909	908	624	-623
2356	1	-7.9	-909	908	623	-622
2357	1	-7.9	-909	908	622	-621
2358	1	-7.9	-909	908	621	-620
2359	1	-7.9	-909	908	620	-619
2360	1	-7.9	-909	908	619	-618
2361	1	-7.9	-909	908	618	-617
2362	1	-7.9	-909	908	617	-616
2363	1	-7.9	-909	908	616	-615
2364	1	-7.9	-909	908	615	-614
2365	1	-7.9	-909	908	614	-613
2366	1	-7.9	-909	908	613	-612
2367	1	-7.9	-909	908	612	-611
2368	1	-7.9	-909	908	611	-610
2369	1	-7.9	-909	908	610	-609
2370	1	-7.9	-909	908	609	-608
2371	1	-7.9	-909	908	608	-607
2372	1	-7.9	-909	908	607	-606
2373	1	-7.9	-909	908	606	-605
2374	1	-7.9	-909	908	605	-604
2375	1	-7.9	-909	908	604	-603
2376	1	-7.9	-909	908	603	-602
2377	1	-7.9	-909	908	602	-601
2378	1	-7.9	-909	908	601	-146
C						
2379	0	-905	908	-22		
C						
2380	1	-7.9	754	-926	-908	910
2381	1	-7.9	754	-926	-910	911
2382	1	-7.9	754	-926	-911	912
2383	1	-7.9	754	-926	-912	913
2384	1	-7.9	754	-926	-913	914
2385	1	-7.9	754	-926	-914	915
2386	1	-7.9	754	-926	-915	916
2387	1	-7.9	754	-926	-916	917
2388	1	-7.9	754	-926	-917	918
2389	1	-7.9	754	-926	-918	919
2390	1	-7.9	754	-926	-919	920
2391	1	-7.9	754	-926	-920	921
2392	1	-7.9	754	-926	-921	922

\$ DEBRIS SHIELD (1/2" THICK SS)

```

2393 1 -7.9 754 -926 -922 923
2394 1 -7.9 754 -926 -923 924
2395 4 -8.96 -924 925 -760 $ COPPER LID ON DEBRIS SHIELD
2396 4 -8.96 -924 925 760 -761
2397 4 -8.96 -924 925 761 -748
2398 4 -8.96 -924 925 748 -749
2399 4 -8.96 -924 925 749 -750
2400 4 -8.96 -924 925 750 -751
2401 4 -8.96 -924 925 751 -752
2402 4 -8.96 -924 925 752 -753
2403 4 -8.96 -924 925 753 -754
2404 4 -8.96 -924 925 754 -755 $ COPPER LID ON DEBRIS SHIELD
2405 1 -7.9 -927 924 926 -762 $ RINGS ON TOP OF DEBRIS SHIELD
2406 1 -7.9 -925 928 926 -762
2407 0 -908 924 -754 936 $ VOID INSIDE DEBRIS SHIELD
2408 0 -908 927 926 -762
2409 0 -924 925 755 -762
2410 0 -908 928 762 -146
2411 0 -925 928 -926
C
2412 1 -7.9 146 -147 -908 910 $ EXTENSION OF STACK TO TOP OF
2413 1 -7.9 146 -147 -910 911 $ DEBRIS SHIELD
2414 1 -7.9 146 -147 -911 912
2415 1 -7.9 146 -147 -912 913
2416 1 -7.9 146 -147 -913 914
2417 1 -7.9 146 -147 -914 915
2418 1 -7.9 146 -147 -915 916
2419 1 -7.9 146 -147 -916 917
2420 1 -7.9 146 -147 -917 918
2421 1 -7.9 146 -147 -918 919
2422 1 -7.9 146 -147 -919 920
2423 1 -7.9 146 -147 -920 921
2424 1 -7.9 146 -147 -921 922
2425 1 -7.9 146 -147 -922 923
2426 1 -7.9 146 -147 -923 924
2427 1 -7.9 146 -147 -924 925
2428 1 -7.9 146 -147 -925 928
C
2429 10 -1.19 18 -460 931 -452 929 -930
2430 10 -1.19 18 -460 452 -454 929 -930
2431 10 -1.19 18 -460 454 -456 929 -930
2432 7 -2.7 671 -18 931 -456 929 -930
2433 7 -2.7 460 -672 931 -456 929 -930
2434 0 671 -672 669 -431 933 -932
2435 7 -2.7 671 -672 933 -929 -669
2436 7 -2.7 671 -672 930 -932 -669
2437 0 671 -672 932 -431
2438 0 671 -672 -933 -431
C
2439 0 -936 $ LOCATION OF SOURCE
C
2440 0 937 -489 137 -450
C
C 2441 0 26 -677 147 -938 $ OUTSIDE MACHINE
C 2442 0 -26 939 -938 $ " "
C 2443 0 677 -940 -938 $ " "
C 2444 0 -939:940:938 $ UNIVERSE OUTSIDE -- KILL ZONE
C 2445 0 941 -942 -943 944 -945 $ COOKIE-CUTTER CELL
C
2441 0 -26:677:147 $ Universe outside -- Kill Zone
C *****
C SURFACES
1 py 0.0
2 py 0.635
3 py 1.905
4 py 2.54
5 py 3.81
6 py 4.445
7 py 5.715
8 py 6.35
9 py 7.62

```

```

10  py 8.89
11  cy 3.175          $ 2.5" hole thru top SS plate
12  cy 8.89
13  py 10.16
c 14  py 35.16
c 15  py 58.89
16  py 127.6096
17  py 150.0632
18  1 py 56.48544
c 19  py 719.62
20  cy 121.963180
21  cy 125.215904
22  ky -28.909206 0.64 1  $ Outer MITL Cone
23  ky -24.843329 0.64 1  $ Inner MITL Cone
24  cy 6.35          $ Cylinder to match original
c          Tungsten insert
25  ky -129.54 0.000517 1  $ Collimator Cone
c
26  py -62.0        $ Plane above Debris Shield
27  py 11.43
28  py 12.7
29  py 13.97
30  py 15.24
31  py 16.51
32  py 17.78
33  py 19.05
34  py 20.32
35  py 21.59
36  py 22.86
37  py 24.13
38  py 25.4
39  py 26.67
40  py 27.94
41  py 29.21
42  py 30.48
43  py 31.75
44  py 33.02
45  py 34.29
46  py 35.56
47  py 36.83
48  py 38.1
49  py 39.37
50  py 40.64
51  py 41.91
52  py 43.18
53  py 44.45
54  py 45.72
55  py 46.99
56  py 48.26
57  py 49.53
58  py 50.8
59  py 52.07
60  py 53.34
61  py 54.61
62  py 55.88
63  py 57.15
64  py 58.42
65  py 59.69
66  py 60.96
67  py 62.23
68  py 63.5
69  py 64.77
70  py 66.04
71  py 67.31
72  py 68.58
73  py 69.85
74  py 71.12
75  py 72.39
76  py 73.66
77  py 74.93
78  py 76.2
79  py 77.47

```

```

80 py 78.74
81 py 80.01
82 py 81.28
83 py 82.55
84 py 83.82
85 py 85.09
86 py 86.36
87 py 87.63
88 py 88.9
89 py 90.17
90 py 91.44
91 py 92.71
92 py 93.98
93 py 95.25
94 py 96.52
95 py 97.79
96 py 99.06
97 py 100.33
98 py 101.6
99 py 102.87
100 py 104.14
101 py 105.41
102 py 106.68
103 py 107.95
104 py 109.22
105 py 110.49
106 py 111.76
107 py 113.0
108 py 114.3
109 py 115.57
110 py 116.84
111 py 118.11
112 py 119.38
113 py 120.65
114 py 121.92
115 py 123.19
116 py 124.46
117 py 125.73
c 118 py 127.6096
119 py 128.8796
120 py 130.1496
121 py 131.4196
122 py 132.6896
123 py 133.9596
124 py 135.2296
125 py 136.4996
126 py 137.7696
127 py 139.0396
128 py 140.3096
129 py 141.5796
130 py 142.8496
131 py 144.1196
132 py 145.3896
133 py 146.6596
134 py 147.9296
135 py 149.1996
c 136 py 150.0632
137 1 cy 3.81 $ OUTER DIA OF SCINTILLATOR
c 138 cy 54.61
139 py 60.97
140 cy 18.0
141 ky -20.777452 0.64 1 $ Cone for space b/w TIVAR & MITL
142 ky -30.48 0.021207 1 $ TIVAR cone to shadow pig
c to twice it's radius
c
143 ky -30.545720 0.6780965 1 $ Inner MITL Cone #2
144 ky -35.541454 0.6780965 1 $ Outer MITL Cone #2
145 py 139.336834 $ Base of MITL Cone #2
146 cy 160.02 $ Radius of Stack (5' 3")
147 cy 162.56 $ Outer radius of stack (1" thick)
148 py 500.4562 $ Bottom of Stack
149 py 188.55436 $ Bottom of MITL #1 Cylinder

```

c
 150 py 151.3332
 151 py 152.6032
 152 py 153.8732
 153 py 155.1432
 154 py 156.4132
 155 py 157.6832
 156 py 158.9532
 157 py 160.2232
 158 py 161.4932
 159 py 162.7632
 160 py 164.0332
 161 py 165.3032
 162 py 166.5732
 163 py 167.8432
 164 py 169.1132
 165 py 170.3832
 166 py 171.6532
 167 py 172.9232
 168 py 174.1332
 169 py 175.4632
 170 py 176.7332
 171 py 178.0032
 172 py 179.2732
 173 py 180.5432
 174 py 181.8132
 175 py 183.0832
 176 py 184.3532
 177 py 185.6232
 178 py 186.8932
 179 py 188.1632
 c
 180 py 190.0
 181 py 191.25
 182 py 192.5
 183 py 193.75
 184 py 195.0
 185 py 196.25
 186 py 197.5
 187 py 198.75
 188 py 200.0
 189 py 201.25
 190 py 202.5
 191 py 203.75
 192 py 205.0
 193 py 206.25
 194 py 207.5
 195 py 208.75
 196 py 210.0
 197 py 211.25
 198 py 212.5
 199 py 213.75
 200 py 215.0
 201 py 216.25
 202 py 217.5
 203 py 218.75
 204 py 220.0
 205 py 221.25
 206 py 222.5
 207 py 223.75
 208 py 225.0
 209 py 226.25
 210 py 227.5
 211 py 228.75
 212 py 230.0
 213 py 231.25
 214 py 232.5
 215 py 233.75
 216 py 235.0
 c
 217 py 236.25
 218 py 237.5

219	py	238.75
220	py	240.0
221	py	241.25
222	py	242.5
223	py	243.75
224	py	245.0
225	py	246.25
226	py	247.5
227	py	248.75
228	py	250.0
229	py	251.25
230	py	252.5
231	py	253.75
232	py	255.0
233	py	256.25
234	py	257.5
235	py	258.75
236	py	260.0
237	py	261.25
238	py	262.5
239	py	263.75
240	py	265.0
241	py	266.25
242	py	267.5
243	py	268.75
244	py	270.0
245	py	271.25
246	py	272.5
247	py	273.75
248	py	275.0
249	py	276.25
250	py	277.5
251	py	278.75
252	py	280.0
253	py	281.25
254	py	282.5
255	py	283.75
256	py	285.0
257	py	286.25
258	py	287.5
259	py	288.75
260	py	290.0
261	py	291.25
262	py	292.5
263	py	293.75
264	py	295.0
265	py	296.25
266	py	297.5
267	py	298.75
268	py	300.0
269	py	301.25
270	py	302.5
271	py	303.75
272	py	305.0
273	py	306.25
274	py	307.5
275	py	308.75
276	py	310.0
277	py	311.25
278	py	312.5
279	py	313.75
280	py	315.0
281	py	316.25
282	py	317.5
283	py	318.75
284	py	320.0
285	py	321.25
286	py	322.5
287	py	323.75
288	py	325.0
289	py	326.25
290	py	327.5

291	py 328.75
292	py 330.0
293	py 331.25
294	py 332.5
295	py 333.75
296	py 335.0
297	py 336.25
298	py 337.5
299	py 338.75
300	py 340.0
301	py 341.25
302	py 342.5
303	py 343.75
304	py 345.0
305	py 346.75
306	py 347.5
307	py 348.75
308	py 350.0
309	py 351.25
310	py 352.5
311	py 353.75
312	py 355.0
313	py 356.25
314	py 357.5
315	py 358.75
316	py 360.0
317	py 361.25
318	py 362.5
319	py 363.75
320	py 365.0
321	py 366.25
322	py 367.5
323	py 368.75
324	py 370.0
325	py 371.25
326	py 372.5
327	py 373.75
328	py 375.0
329	py 376.25
330	py 377.5
331	py 378.75
332	py 380.0
333	py 381.25
334	py 382.5
335	py 383.75
336	py 385.0
337	py 386.25
338	py 387.5
339	py 388.75
340	py 390.0
341	py 391.25
342	py 392.5
343	py 393.75
344	py 395.0
345	py 396.25
346	py 397.5
347	py 398.75
348	py 400.0
349	py 401.25
350	py 402.5
351	py 403.75
352	py 405.0
353	py 406.25
354	py 407.5
355	py 408.75
356	py 410.0
357	py 411.25
358	py 412.5
359	py 413.75
360	py 415.0
361	py 416.25
362	py 417.5

363	py	418.75	
364	py	420.0	
365	py	421.25	
366	py	422.5	
367	py	423.75	
368	py	425.0	
369	py	426.25	
370	py	427.5	
371	py	428.75	
372	py	430.0	
373	py	431.25	
374	py	432.5	
375	py	433.75	
376	py	435.0	
377	py	436.25	
378	py	437.5	
379	py	438.75	
380	py	440.0	
381	py	441.25	
382	py	442.5	
383	py	443.75	
384	py	445.0	
385	py	446.25	
386	py	447.5	
387	py	448.75	
388	py	450.0	
389	py	451.25	
390	py	452.5	
391	py	453.75	
392	py	455.0	
393	py	456.25	
394	py	457.5	
395	py	458.75	
396	py	460.0	
397	py	461.25	
398	py	462.5	
399	py	463.75	
400	py	465.0	
401	py	466.25	
402	py	467.5	
403	py	468.75	
404	py	470.0	
405	py	471.25	
406	py	472.5	
407	py	473.75	
408	py	475.0	
409	py	476.25	
410	py	477.5	
411	py	478.75	
412	py	480.0	
413	py	481.25	
414	py	482.5	
415	py	483.75	
416	py	485.0	
417	py	486.25	
418	py	487.5	
419	py	488.75	
420	py	490.0	
421	py	491.25	
422	py	492.5	
423	py	493.75	
424	py	495.0	
425	py	496.25	
426	py	497.5	
427	py	498.75	
c			
428	1 py	71.72544	
429	1 py	74.26544	
430	1 py	76.80544	\$ BOTTOM OF PIG
431	1 cy	26.67	\$ ID of Pb/W "Box"; 21" ID
432	1 cy	27.94	
433	1 cy	30.48	

C
 434 1 py 26.00544
 435 1 py 28.54544
 436 1 py 31.08544
 437 1 py 33.62544
 438 1 py 36.16544
 439 1 py 38.70544
 440 1 py 41.24544
 441 1 py 43.78544
 442 1 py 46.32544
 443 1 py 48.86544
 444 1 py 51.40544
 445 1 py 53.94544
 446 1 py 61.56544
 447 1 py 64.10544
 448 1 py 66.64544
 449 1 py 69.18544
 450 1 cy 5.08
 451 1 cy 7.62
 452 1 cy 10.16
 453 1 cy 12.7
 454 1 cy 15.24
 455 1 cy 17.78
 456 1 cy 20.32
 457 1 cy 22.86
 458 1 cy 25.40
 c 459 cy 27.94 \$ Same as 432
 460 1 py 59.025440
 461 1 cy 1.27
 C
 c 462 py 719.5225
 C
 c 463 py 699.78
 c 464 py 702.32
 c 465 py 704.86
 c 466 py 707.40
 c 467 py 709.94
 c 468 py 712.48
 c 469 py 715.02
 c 470 py 717.56
 C
 471 1 py -1.934560
 C
 472 1 py 0.0 \$ PIVOT POINT OF PIG
 473 1 py 3.14544
 474 1 py 5.68544
 475 1 py 8.22544
 476 1 py 10.76544
 477 1 py 13.30544
 478 1 py 15.84544
 479 1 py 18.38544
 480 1 py 20.92544
 481 1 py 23.46544
 C
 482 1 py -5.05206
 483 1 py -7.59206
 484 1 py -10.13206
 485 1 py -12.67206
 486 1 py -15.21206
 487 1 py -17.75206
 488 1 py -20.29206
 489 1 py -22.83206
 490 1 py -25.37206
 491 1 py -27.91206
 492 1 py -30.45206
 493 1 py -32.99206
 494 1 py -35.53206
 495 1 py -38.07206
 496 1 py -40.61206
 497 1 py -43.15206
 498 1 py -45.69206
 499 1 py -48.23206

C
 500 1 py -50.77206
 501 1 py -53.31206
 502 1 py -55.85206
 503 1 py -58.39206
 C
 504 1 py -60.93206
 C
 C 505 py 636.28
 C 506 py 633.74
 C 507 py 631.20
 508 1 cy 33.02
 C
 509 1 cy 34.29 \$ RADIUS OF PIG
 C
 C 510 cy 30.48 \$ Outer dia of TIVAR (2ft dia); same as 433
 C
 C ***** BOTTOM LID ADDITION *****
 C
 600 py 498.5512 \$ Vacuum Side of Bottom Lid (3/4" thick)
 601 cy 157.48
 602 cy 154.94
 603 cy 152.40
 604 cy 149.86
 605 cy 147.32
 606 cy 144.78
 607 cy 142.24
 608 cy 139.70
 609 cy 137.16
 610 cy 134.62
 611 cy 132.08
 612 cy 129.54
 613 cy 127.00
 614 cy 124.46
 615 cy 121.92
 616 cy 119.38
 617 cy 116.84
 618 cy 114.30
 619 cy 111.76
 620 cy 109.22
 621 cy 106.68
 622 cy 104.14
 623 cy 101.60
 624 cy 99.06
 625 cy 96.52
 626 cy 93.98
 627 cy 91.44
 628 cy 88.90
 629 cy 86.36
 630 cy 83.82
 631 cy 81.28
 632 cy 78.74
 633 cy 76.20
 634 cy 73.66
 635 cy 71.12
 636 cy 68.58
 637 cy 66.04
 638 cy 63.50
 639 cy 60.96
 640 cy 58.42
 641 cy 55.88
 642 cy 53.34
 643 cy 50.80
 644 cy 48.26
 645 cy 45.72
 646 cy 43.18
 647 cy 40.64
 648 cy 38.10
 649 cy 35.56
 C 650 cy 33.02 \$ SAME AS 508
 C 651 cy 30.48 \$ SAME AS 433
 C 652 cy 27.94 \$ SAME AS 432

c 653 cy 25.40 \$ SAME AS 458
 c 654 cy 22.86 \$ SAME AS 457
 c 655 cy 20.32 \$ SAME AS 456
 c 656 cy 17.78 \$ SAME AS 455
 c 657 cy 15.24 \$ SAME AS 454
 c 658 cy 12.70 \$ SAME AS 453
 c 659 cy 10.16 \$ SAME AS 452
 c 660 cy 7.62 \$ SAME AS 451
 c 661 cy 5.08 \$ SAME AS 450
 662 py 502.3612
 663 py 504.1392
 664 py 497.12245 \$ 9/16" SHIELD PLATE
 665 cy 2.54
 666 1 py -22.51456
 667 1 py -19.97456
 668 1 py -19.65706 \$ ***** END OF BOTTOM LID ADDITION *****
 c
 669 1 cy 20.955
 670 1 py -21.24456
 c
 671 1 py 56.16794
 672 1 py 59.34294
 673 1 py 57.75544
 c
 c 674 cy 2.54 \$ 2" HOLE THRU COPPER PLATES
 c
 675 py 495.6937 \$ 9/16" COPPER PLATE ABOVE SHIELD PLATE
 c
 676 py 850.275 \$ ELEVATOR FLOOR 20.25" B/L PIG
 677 py 852.815 \$ THICKNESS OF ELEVATOR (1")
 c
 678 1 cy 29.21 \$ TO "STAGGER" W PLUG
 c
 679 1 py -39.34206
 c
 c *****
 c NOTE: SIDE PLATES ON PIG ARE IN CORRECT POSITION
 c (i.e., ON SIDES WHERE YOKE ATTACHES)
 c
 680 pz 35.56 \$ OUTER PLANE OF SIDE PLATES ON PIG
 c
 681 1 px -19.685 \$ WIDTH OF SIDE PLATES 7.75"
 682 1 px 19.685 \$ " " " " "
 683 pz 28.076768
 c
 684 pz -35.56 \$ OUTER PLANE OF SIDE PLATES ON PIG
 685 pz -28.076768
 c
 c *****
 c
 686 1 py -63.47206
 687 1 py -66.01206
 688 1 py -68.55206
 689 1 py -71.09206
 690 1 py -73.63206
 c
 691 1 py -76.17206
 c
 692 1 cy 3.811 \$ SURFACE 692 TRANSFORMED BELOW
 c
 693 1 py -78.71206
 694 1 py -81.25206
 695 1 py -83.15706
 696 1 py -86.01456
 697 1 py -88.87206
 698 1 py -91.41206
 699 1 py -93.95206
 700 1 py -96.49206
 701 1 py -99.03206
 702 1 py -101.57206
 703 1 py -104.11206
 704 1 py -106.65206

705 1 py -109.19206
 706 1 py -111.73206
 707 1 py -114.27206
 708 1 py -116.81206
 709 1 py -119.35206
 710 1 py -121.89206
 711 1 py -124.43206
 712 1 py -126.97206
 713 1 py -129.51206
 714 1 py -132.05206
 715 1 py -134.59206
 716 1 py -136.49706
 717 1 py -139.67206
 718 1 py -142.21206
 719 1 py -144.75206
 720 1 py -147.29206
 c 721 1 py -149.83206
 c 722 1 py -152.37206
 c
 723 1 py -120.62206
 724 1 py -123.16206
 725 1 py -125.70206
 726 1 py -128.24206
 727 1 py -130.78206
 728 1 py -133.32206
 729 1 py -135.86206
 730 1 py -138.40206
 731 1 py -140.94206
 732 1 py -143.48206
 733 1 py -146.02206
 734 1 py -148.56206
 c 735 1 py -151.10206
 c
 736 1 py -118.08206
 737 1 py -115.54206
 738 1 py -113.00206
 739 1 py -110.46206
 740 1 py -107.92206
 741 1 py -105.38206
 742 1 py -102.84206
 743 1 py -100.30206
 744 1 py -97.76206
 745 1 py -95.22206
 746 1 py -92.68206
 747 1 py -90.14206
 c
 748 cy 5.08 \$ SAME AS 450 B/F TRANSLATION
 749 cy 7.62 \$ " " 451 " "
 750 cy 10.16 \$ " " 452 " "
 751 cy 12.7 \$ " " 453 " "
 752 cy 15.24 \$ " " 454 " "
 753 cy 17.78 \$ " " 455 " "
 754 cy 20.32 \$ " " 456 " "
 755 cy 22.86 \$ " " 457 " "
 756 cy 25.4 \$ " " 458 " "
 757 cy 27.94 \$ " " 432 " "
 758 cy 30.48 \$ " " 433 " "
 759 cy 33.02 \$ " " 508 " "
 760 cy 1.27 \$ " " 461 " "
 761 cy 3.81 \$ " " 137 " "
 762 cy 26.67 \$ " " 431 " "
 c
 763 c/y 27.94 0 2.54 \$ x z R
 764 c/y 27.94 0 5.08
 765 c/y 27.94 0 7.62
 766 c/y 27.94 0 10.16
 767 c/y 27.94 0 12.7
 c
 c 768 1 py -154.91206 \$ SURFACES FOR 4 FOOT
 c 769 1 py -157.45206 \$ POLY COLLIMATOR
 c 770 1 py -159.99206 \$ (TURNS OUT, 4 FEET IS
 c 771 1 py -162.53206 \$ TOO LONG)

c 772 1 py -165.07206
 c 773 1 py -167.61206
 c 774 1 py -170.15206
 c 775 1 py -172.69206
 c 776 1 py -175.23206
 c 777 1 py -177.77206
 c 778 1 py -180.31206
 c 779 1 py -182.85206
 c
 780 1 cy 35.56
 781 1 cy 38.1
 c
 782 1 cy 38.735
 c
 784 py 819.82456001
 785 py 822.3645999 \$ 822.2
 786 py 823.634567
 c
 c 787 cy 55.88
 c
 c 788 px 55.88
 c 789 pz 55.88
 c
 c 790 px -55.88
 c 791 pz -55.88
 c
 c BOTTOM CHASSIS OF PIG:
 c
 792 BOX -41.91 822.36456001 -41.91001 83.820001 0 0 0 1.27 0 0 0 83.82
 c
 793 2 BOX -39.437617 -13.9699901 0 83.82 0 0 0 16.001 0 0 0 1.2701
 c
 794 3 BOX -39.437617 -13.970001 -1.3 83.82001 0 0 0 16 0 0 0 1.27
 c
 795 BOX -41.91 801 -54.1 83.82 0 0 0 11.43 0 0 0 1.27001
 c
 796 BOX -41.91 811.59 -54.101 83.8201 0 0 0 1.27 0 0 0 3.29
 c
 797 BOX -41.91 801 52.9 83.81999 0 0 0 11.43 0 0 0 1.27
 c
 798 BOX -41.91 811.5 50.87 83.820001 0 0 0 1.27 0 0 0 3.3
 c
 799 BOX -19.85 819.82456 -19.587517 39.7002 0 0 0 2.54 0 0 0 39.7002
 c
 c BOTTOM OF YOKE: 4" x 8" x 1/4"
 c
 800 BOX -10.16 809.66456 -39.37 20.32 0 0 0 10.16 0 0 0 78.74
 c
 801 BOX -9.525 810.29956 -39.37 19.05 0 0 0 8.89 0 0 0 78.74
 c
 c **** SURFACES TO EXTEND MITL CONES/DEBRIS SHIELD ****
 900 py -1.82
 901 py -4.36
 902 py -6.9
 903 py -9.44
 904 py -11.98
 905 py -14.521
 906 py -17.061
 907 py -19.601
 908 py -21.2985
 909 py -18.7585
 910 py -23.8385
 911 py -26.3785
 912 py -28.9185
 913 py -31.4585
 914 py -33.9985
 915 py -36.5385
 916 py -39.0785
 917 py -41.6185
 918 py -44.1585
 919 py -46.6985
 920 py -49.2385

```

921 py -51.7785
922 py -54.3185
923 py -56.8585
924 py -57.4935 $ Top Inside Height of Copper Lid
925 py -60.0335 $ Top of Copper Lid (1" Thick)
926 cy 21.54 $ OD of DEBRIS SHIELD
927 py -56.2235
928 py -61.3035
c
929 1 pz -5.08
930 1 pz 5.08
931 1 cy 4.65
932 1 pz 5.715
933 1 pz -5.715
934 1 cz 62.8
935 1 cy 4.1275
936 sy -30.48 0.5 $ sy y R -- Location of Source
937 1 py -24.10206
c
c 938 cy 300.0
c 939 py -200.0
c 940 py 1000.0
c
c 941 py -100.0 $ Top of Cookie Cutter Cell
c 942 py 900.0 $ Bottom of Cookie Cutter Cell
c 943 4 px 0.001
c 944 4 pz 0.001
c 945 cy 180.0

c isotropic fusion point source at (0,-30.48,0)
c
mode n p
c
sdef par=1 erg=d2 pos=0 -30.48 0 $ dir=d1 vec=0 1 0
c
c si1 -1 0.173648 1 $ Cone Bias -1 cos(theta) +1
c sp1 0 0.586824 0.413176 $ Cone Bias (theta = 80 deg)
c sb1 0 0.001 0.999 $ Cone Bias
sp2 -4 -0.002 -2 $ -4 Fusion Source; 0.002 MeV = 2keV;
c 2 is DD Source, 1 is DT Source
c
c Air at Sea Level (TO ILLUSTRATE SOURCE LOCATION)
c m11 7014.50c -0.765 &
c 8016.50c -0.235
c
c Tungsten
m2 74000.55c 1
c
c SCINTILLATOR [BC-418 OR BC-422Q]
m6 1001.60c 1.1 6000.60c 1 $ NOTE: CHANGED FROM .50c TO .60c
c
c Copper Plates
m4 29000.50c 1
c
c Lead
m5 82000.50c 1
c
c Aluminum G-15 (MCNP5 Manual)
m7 13027.50c 1
c
c High Molecular Weight Polyethylene
c TIVAR 1000
m3 1001.50c 2 6000.50c 1
c
c Steel (FOR BOTTOM LID; 97.96% Fe, 2.04% C)
m8 26000.55c -0.9796 6000.50c -0.0204
c
c Polyethylene Collimator on top of Pig (C2H4)
m9 1001.50c 4 6000.50c 2
c
c Lucite Light Guides (Density = 1.19 g/cc)
m10 1001.60c -0.080538 6000.60c -0.599848 8016.60c -0.319614

```

```

C
C Stainless Steel (67.5% Fe, 19% Cr, 10% Ni, 2% Mn, 1% Si, 0.5% Cu) G-13
m1 26000.55c -67.5 24000.50c -19.0 28000.50c -10.0 25055.51c -2.0 &
14000.51c -1.0 29000.50c -0.5
C
C *****
C CELL IMPORTANCES:
C
imp:n 1 1943r 0
C
imp:p 1 1943r 0
C
C *****
C
C **** CELL TRANSFORMATION CARD *****
C (FOR HOLE THRU POLY & PIG -- 3.0 DEGREE TILT)
C PIG IS SET AT ACTUAL FIELDIED POSITION, 3 DEG OFF AXIS
C
C ORIGIN OF x', y', z' COORD SYSTEM:
C 39.437617 722.03456 0
C
C HOWEVER, PUTTING PIG BACK ON AXIS,
C SO NO TRANSFORMATION
C
C x - x': 360.0 DEGREES
C y - x': 270.0 DEGREES
C z - x': 90 DEGREES
C
C x - y': 90.0 DEGREES
C y - y': 360.0 DEGREES
C z - y': 90 DEGREES
C
C x - z': 90 DEGREES
C y - z': 90 DEGREES
C z - z': 0 DEGREES
C
C
C *TR1 39.437617 722.03456 0 357.0 267.0 90 87.0 357.0 90 90 90 0 1
C
C *****
C
C **** CELL TRANSFORMATION CARDS (FOR PART OF CHASSIS) ****
C
*TR2 -2.472383 822.36456 -41.91 0 90 90 90 45 45 90 135 45 1
C
*TR3 -2.472383 822.36456 41.91 0 90 90 90 45 45 90 45 45 1
C
C *** TRANSFORMATION FOR COOKIE CUTTER CELL ***
C
*TR4 0 0 0 45 90 135 90 0 90 135 90 225
C *****
C WEIGHT WINDOW GENERATOR CARD
C
WWG 5 0 $ Ask WW Generator to find weights
C 5 - Tally ; 1 - Source Cell; 0 - Use mesh-based
C generator (MESH Card)
C
C MESH-BASED WEIGHT WINDOW GENERATOR:
C
C NOTE: ORIGIN AT LOWER LEFT; IMESH, JMESH, KMESH ARE COORDINATES
C OF UPPER RIGHT, COVERING ALL GEOMETRY.
C
mesh geom rec origin -163 -62.5 -163 ref 0 -62.4 0
C
C **** NOTE: FOR MCNP4C, 2 COARSE MESHES PER DIRECTION ARE REQ'D!! ****
C
C imesh 0.0 163 iints 25 25 $ 2 COARSE MESHES B/W -163 TO 0.0
C AND 0.0 TO +163
C jmesh 395.9 853 jints 25 25 $ 2 COARSE MESHES B/W -62.5 TO 395.9
C AND 395.9 TO 853 <== TO ELEVATOR!!
C kmesh 0.0 163 kints 25 25 $ 2 COARSE MESHES B/W -163 TO 0.0
C AND 0.0 TO 163

```

```

C
C *****
C
C WEIGHT WINDOW PARAMETER CARD
C
C WWP:n 4j -1      $ <=== -1 TO GET WT WINDOW LOWER BOUNDS
C                  FROM EXTERNAL WWINP FILE
C
C ***** DXTRAN CARD *****
C ***** TOP nTOF *****
C
C NOTE: DIFFERENT COORDS x,y,z SINCE
C TRANSFORMING PIG TO 3 DEGREE TILT
C
C      x      y      z      RI1 RI2 DWC1  DWC2 DPWT
C      |      |      |      |   |   |   |   |   |
DXT:n 42.464451 779.79 0 4.6 4.6 1000.0 0.0 0.001
C
C 1000.0 = UPPER WT CUTOFF IN SPHERE (DWC1)
C 0.0     = LOWER WT CUTOFF IN SPHERE (DWC2)
C 0.001   = MINIMUM PHOTON WT (DPWT)
C
C *****
C ***** FORCED COLLISIONS CARD *****
C FOR CELL 276 (SCINTILLATOR)
C
C w/ xi = -1, FORCED COLLISION ONLY APPLIES
C TO PARTICLES ENTERING THE CELL
C
C      xi = -1
C      |
FCL:n 0 204R -1 0 1738R
C
C *****
C VOLUME CARD FOR SCINTILLATOR CELL (276)
C (NEED TO INCLUDE IT B/C OF TRANSFORMATION;
C F4 AND F6 TALLIES BELOW NEED IT)
C
VOL 205J 115.83333 1739J
C
C *****
C PHOTON PRODUCTION BIAS CARD (PIKMT)
C
C (LOOKING AT NEUTRON-INDUCED PHOTON PRODUCTION
C NOTE: ALL PHOTON PRODUCTION DONE WITH NORMAL
C SAMPLING TECHNIQUES)
C
C PIKMT ZAID(1) ipik(1) mt(1) pmt(1)
C
C ZAID FOR H
C
C      |      |      |      |
C      |      |      |      | ipik > 0, photon production is biased for ZAID(1);
C      |      |      |      | [if ipik = 0, photons produced from ZAID(1)
C      |      |      |      | are done with normal sampling techniques]
C      |      |      |      |
C      |      |      |      | MT = reaction identifier for the photon-production
C      |      |      |      | to be sampled (in this case, 102 = n,gamma;
C      |      |      |      | (only used if ipik>0)
C      |      |      |      |
C      |      |      |      | Controls the frequency with which the specified
C      |      |      |      | MT reactions are sampled (only used if ipik>0)
C      |      |      |      |
PIKMT 1001 0 $ 102 1
C
C 6000 0 $ <== photons produced from Carbon
C
C 13027 0 $ <== photons produced from Aluminum

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C      26000 0 $ <== photons produced from Iron
C
C      74000 0 $ <== photons produced from Tungsten
C
C      82000 0 $ <== photons produced from Lead
C
C      *****
C      PHOTON WEIGHT CARD (PWT) (COMMENTED OUT)
C
C      [CONTROLS THE NUMBER AND WEIGHT OF NEUTRON-INDUCED PHOTONS
C      PRODUCED AT NEUTRON COLLISIONS. ONLY PROMPT PHOTONS ARE
C      PRODUCED FROM NEUTRON COLLISIONS. DELAYED GAMMAS ARE
C      NEGLECTED BY MCNP.]
C
C      PWT W1 W2 W3 ... WI (DEFAULT VALUE: Wi = -1)
C
C      PWT -1 1943r 0
C
C      *****
C      TALLY n FLUX @ DETECTOR AND PIG:
C
C      F4 @ Detector:
f4:n 276
t4 35.5 36 36.1 36.2 36.3 36.4 36.5 36.6 36.7 36.8
    36.9 37.0 37.1 37.2 37.3 37.4 37.5 37.6 37.7 37.8
    37.9 38.0 38.1 38.2 38.3 38.4 38.5 38.6 38.7 38.8
    38.9 39.0 39.1 39.2 39.3 39.4 39.5 39.6 39.7 39.8
    39.9 40.0 40.1 40.2 40.3 40.4 40.5 40.6 40.7 40.8
    40.9 41.0 41.1 41.2 41.3 41.4 41.5 41.6 41.7 41.8
    41.9 42.0 42.1 42.2 42.3 42.4 42.5 42.6 42.7 42.8
    42.9 43.0 43.1 43.2 43.3 43.4 43.5 43.6 43.7 43.8
    43.9 44.0 44.1 44.2 44.3 44.4 44.5 44.6 44.7 44.8
    44.9 45.0 45.1 45.2 45.3 45.4 45.5 45.6 45.7 45.8
    45.9 46.0 46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8
    46.9 47.0 47.1 47.2 47.3 47.4 47.5 47.6 47.7 47.8
    47.9 48.0 48.1 48.2 48.3 48.4 48.5 48.6 48.7 48.8
    48.9 49.0 49.1 49.2 49.3 49.4 49.5 49.6 49.7 49.8
    49.9 50.0 50.1 50.2 50.3 50.4 50.5 50.6 50.7 50.8
    50.9 51.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 t
C
C      *****
C      POINT DETECTOR RIGHT IN THE MIDDLE OF THE SCINTILLATOR
C
C      Fn:pl x y z R0
C
C      x          y      z      R0
C      |          |      |      |
f5:n 42.464451 779.79 0 4.6
C
C      $ 43.47 = x COORD OF PT DETECTOR
C      (SAME AS DXTRAN SPHERE)
C
C      $ 779.79 = Y COORD OF PT DETECTOR
C      (SAME AS DXTRAN SPHERE)
C
C      $ 0 = Z COORD OF PT DETECTOR
C
C      $ R0 = RADIUS OF SPHERE OF EXCLUSION
C      (INCLUDES SCINTILLATOR AND ALUMINUM SHELL;
C      SAME AS DXTRAN SPHERE ABOVE)
C
C      *****
C
C      F6 ENERGY DEPOSITED IN SCINTILLATOR
f6:n 276
t6 35.5 36 36.1 36.2 36.3 36.4 36.5 36.6 36.7 36.8
    36.9 37.0 37.1 37.2 37.3 37.4 37.5 37.6 37.7 37.8
    37.9 38.0 38.1 38.2 38.3 38.4 38.5 38.6 38.7 38.8
    38.9 39.0 39.1 39.2 39.3 39.4 39.5 39.6 39.7 39.8
    39.9 40.0 40.1 40.2 40.3 40.4 40.5 40.6 40.7 40.8
    40.9 41.0 41.1 41.2 41.3 41.4 41.5 41.6 41.7 41.8

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41.9 42.0 42.1 42.2 42.3 42.4 42.5 42.6 42.7 42.8
42.9 43.0 43.1 43.2 43.3 43.4 43.5 43.6 43.7 43.8
43.9 44.0 44.1 44.2 44.3 44.4 44.5 44.6 44.7 44.8
44.9 45.0 45.1 45.2 45.3 45.4 45.5 45.6 45.7 45.8
45.9 46.0 46.1 46.2 46.3 46.4 46.5 46.6 46.7 46.8
46.9 47.0 47.1 47.2 47.3 47.4 47.5 47.6 47.7 47.8
47.9 48.0 48.1 48.2 48.3 48.4 48.5 48.6 48.7 48.8
48.9 49.0 49.1 49.2 49.3 49.4 49.5 49.6 49.7 49.8
49.9 50.0 50.1 50.2 50.3 50.4 50.5 50.6 50.7 50.8
50.9 51.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 t
C
C
C nps 1.0E+07 $ 10 Million Particles
C
C PRINT $ Print All Tables
C
C cut:n 85 0 $ Time cutoff --
C lower energy cutoff is zero MeV
C
C ***** MCNP-POLIMI INFORMATION *****
C
C
C PHYS:N J 20.0
C
C PHYS:P 0 1 1
C
C CUT:P 85 J 0 $ CUT:P CARD JUST LIKE CUT:N CARD ABOVE (85 SHAKES)
C
C IDUM 0 0 0 0 J 1 1 276
C
C 1st 0 -- SOURCE ENTIRELY DEFINED IN SDEF CARD
C 2ND 0 -- n'S SAMPLED AS IN STANDARD MCNP
C 3RD 0 -- n COLLISION AND PHOTON PRODUCTION NOT CORRELATED (STD MCNP)
C 4TH 0 -- FOR PHOTON EMISSION @ TIME OF FISSION FOR ALL FISSIONS
C 5TH J -- NOT USED
C 6TH 1 -- COLLISIONS PRINT OUT FOR HISTORIES IN AT LEAST "1" DETECTOR CELL
C 7TH 1 -- NUMBER OF CELLS (DETECTORS) FOR WHICH COLLISION DATA IS REQ'D
C 8TH 276 -- CELL NUMBER FOR COLLISION DATA PRINTOUT
C
C RDUM 0.0 0.0 $ ENERGY DEP BY n'S MUST EXCEED 0.0 eV TO BE PRINTED
C " " " p's " " 0.0 " " " "
C
C FILES 21 DUMN1
C
C *****
C
C MESH TALLY $ NO MESH TALLY TO SAVE TIME
C tmesh
C rmesh1:n flux
C cora1 -162.56 100i 162.56
C corb1 -30.48 100i 739.84
C corc1 -162.56 162.56
C endmd
C
C NOTE: REMOVING TRAKS AND POPUL MESH TALLIES
C TO SHORTEN RUN TIME
C rmesh11:n traks
C cora11 -162.56 100i 162.56
C corb11 -30.48 100i 739.84
C corc11 -162.56 162.56
C rmesh21:n popul
C cora21 -162.56 100i 162.56
C corb21 -30.48 100i 739.84
C corc21 -162.56 162.56
C endmd

```

THE nTOF POST-PROCESSING CODE

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```

if isempty(which(filename)), disp([' -----> ERROR: file ',filename, '
not found']), return, end
%
disp(' ')
%
nTOF=input(' Is this the Top nTOF (1) or Bottom nTOF (2)? : ');
%
disp(' ')
%
coll=input(' Is the Tivar Collimator in place? (1) yes, or (0) no: ');
%
disp(' ')
%
tmin=input(' Enter minimum time in shakes to plot: ');
%
disp(' ')
tmax=input(' Enter max time in shakes to plot: ');
%
disp(' ')
%
digitres=input(' Enter digitizer resolution in (ns): ');
digitres=digitres/10.0; % Conversion from ns to shakes
disp(' ')
%
writefile=input(' Write results to file ? (0) no (1) yes: ');

tic % starts the stopwatch timer
%
*****
*
%
% BEGIN POSTPROCESSING
%
format loose
format long
disp(' *****')
data=load(filename); % load data file
%
% nrow gets # of rows in data file
% ncol gets # of columns in data file
%
[nrow,ncol]=size(data);
%
newrow=nrow;
%
disp(' ')
disp(' Successfully loaded file')
%
disp(' ')
disp([' Number of rows in file = ',int2str(nrow)])
%
disp(' ')
disp([' tmax = ', num2str(tmax), ' shakes']);
disp(' ')
%
bps = 1.0/digitres; % bins per shake
%

```

```

disp([' bps = ', num2str(bps), ' bins per shake'])
disp(' ')
%
TOF = 0.0;

if(nTOF == 2)
    TOF = (809)/(2.166 * 10); % Arrival time in shakes at bottom
                                % Detector
elseif(nTOF == 1)
    TOF = (730)/(2.166 * 10); % Arrival time in shakes at top
                                % Detector
end
%
disp([' TOF = ', num2str(TOF) ' shakes (Arrival Time)'])
disp(' ')
%
disp([' tmin = ', num2str(tmin), ' Shakes (Start Time to Plot)'])
disp(' ')
%
maxrow = (tmax - tmin)* bps; % Maximum number of rows needed for 200 ps
                                % time bins to plot from neutron arrival
                                % time at detector to tmax

%
maxrow = int16(maxrow) + 1; % Converting to Integer & adding 1
%
disp([' maxrow = ', num2str(maxrow), ' maximum rows required'])
disp(' ')
%
if any(diff(data(:,8))<0)
    data=sortrows(data,8); % sort in terms of increasing times
end
%
% disp(' ')
disp(' Successfully sorted file in terms of increasing times')
%
%
disp(' ')
disp(' *****')
%
%
lout=zeros(nrow,1); % loads lout with zeros
%
% ***** LIGHT OUTPUT
% *****
% convert energy depositions to light (lout)
for j=1:nrow
    if data(j,3)==1 % particle = neutron
        if data(j,5)==1001 % nucleus = hydrogen
            lout(j)=polyval(ncal,data(j,7)); % light output for
energy dep.
%
            elseif floor(data(j,5)/1000)==6 % nucleus = carbon
                lout(j)=data(j,7)*lenc; % light output =
energy deposited * light
%
            else disp(['! error, the struck nucleus is unknown ',
int2str(data(j,5))])

```

```

        end
        elseif (data(j,3)==2 || data(j,3)==3) % particle = photon
            lout(j)=polyval(pcal,data(j,7)); % light output for
energy dep.
        %
        else disp(['! error, the incident particle is unknown ',
int2str(data(j,3))])
        end
    end
    %
    disp(' ')
    disp(' Successfully converted energy depositions to light')
    %
    outputtime=zeros(nrow,1); % loads outputtime with zeros
    outputLO=zeros(nrow,1); % loads outputLO with zeros
    outputboth=zeros(nrow,2); % loads outputboth with zeros
    %
    %
    timeout1=zeros(maxrow,1); % loads zeros into timeout1
    lightout1=zeros(maxrow,1); % loads zeros into lightout1
    %
    % ***** BEFORE SUMMING PULSES *****
    for j=tmin:nrow
        outputtime(j,1) = data(j,8); % time in shakes (x-values)
        %
        outputLO(j,1) = lout(j); % Light Output in MeVee
        %
        outputboth(j,1) = data(j,8);
        outputboth(j,2) = lout(j);
        %
    end
    %
    %
    timebin = zeros(maxrow,1); % loads timebin with zeros
    %
    timebin(1,1) = outputtime(tmin,1); % timebin gets 1st value of
outputtime
    %
    disp(' ')
    disp([' First Time Bin = ', num2str(timebin(1,1))])
    disp(' ')
    %
    disp(' Loading Timebin with bins equal to digitizer resolution from
first value in the data')

% LOADS TIMEBIN WITH 200 ps TIME BINS STARTING AT THE FIRST VALUE
% IN THE DATA
%
for j = 1:maxrow
    timebin(j + 1, 1) = timebin(j,1) + digitres;
end
%
disp(' ')
disp(' Summing Pulses')
% ***** SUMMING PULSES *****
for j = tmin: nrow

```

```

        for i = 1: maxrow
            if((outputtime(j,1) >= timebin(i,1)) && ((outputtime(j,1)<=
timebin(i + 1,1))))

                lightout1(i,1) = lightout1(i,1) + outputLO(j,1);

            end

        end

    end

disp(' ')
disp(' Assigning Time to Middle of Bin')
% ASSIGNING TIME TO MIDDLE OF BIN:
    for j = 1:maxrow % k

        timeout1(j,1) = timebin(j,1) + digitres/2.0;

    end

%
lightout=zeros(maxrow,1);
timeout=zeros(maxrow,1);
timelight=zeros(maxrow,2);

for j=1:maxrow
    timelight(j,1) = timeout1(j,1);
    timelight(j,2) = lightout1(j,1);
    lightout(j,1) = lightout1(j,1);
    timeout(j,1) = timeout1(j,1);
end
%
%
plottools('on', 'figurepalette')
%
% PLOTS LIGHT OUTPUT VS TIME:
%
plot(timeout,lightout)
%
xlabel('Time (shakes)');
ylabel('Light Output (MeVee)');
xlim([tmin tmax]); % FOR BOTTOM nTOF, STARTING AT 30 SHAKES IS FINE
%
if(nTOF==1 && coll==1)
    title('Top nTOF in Basement Pig with Tivar Collimator');
elseif(nTOF==1 && coll==0)
    title('Top nTOF in Basement Pig with no Tivar Collimator');
elseif(nTOF==2 && coll==1)
    title('Bottom nTOF in Basement Pig with Tivar Collimator');
elseif(nTOF==2 && coll==0)
    title('Bottom nTOF in Basement Pig with no Tivar Collimator');
end
%
% write results to file
%
```

```

if writefile==1
%
    ind1=find(filename=='.'); % If '.' in filename, ind1=# of characters
%                               up to '.'
    if ind1
        root=filename(1:ind1-1); % root=filename w/o '.'
    else
        root=filename;          % elseif no '.', root=filename
    end
%
    dlmwrite(root, timelight); % Writes matrix timelight into ASCII format
%                               file using default delimiter ',' to
%                               separate matrix elements; starting at the
%                               first column and first row of filename.
%                               ASCII file takes the name of root (the
%                               filename input at the beginning)
%
end
%
disp(' ')
disp(' Got to here -- end of program')
%
disp(' ')
toc % ends the stopwatch timer
disp(' ')
%
return

```

APPENDIX C

THE CONVOLUTION ("FOLDING IN") CODE

```
% This program folds in a time response of 7.5 ns of our nTOF
% detectors into the calculated values of the detector response
% found with MCNP-PoliMi and postmain_ntof_U (the post-processor)

disp(' ')
filen=input(' Please enter the MCNP-PoliMi Calculated file name:
','s'); % file name
if isempty(which(filen)), disp([' -----> ERROR: file ',filen, '
not found']), return, end
disp(' ')

Fold=input(' Fold in A Gaussian (1) or Actual Time Response (2)? : ');
disp(' ')

tmin=input(' Enter minimum time in shakes to plot: ');
disp(' ')

tmax=input(' Enter max time in shakes to plot: ');
disp(' ')

fileout=input(' Please enter the name you wish for the output file:
','s'); % file name
disp(' ')

writefile=input(' Write results to file ? (0) no (1) yes: ');

tic % starts the stopwatch timer

format loose
format long
disp(' *****')
disp(' ')
zzz=load(filen); % load data file
%
% nrow gets # of rows in data file
% ncol gets # of columns in data file
%
[nrow,ncol]=size(zzz);

% ***** FOLDING IN THE GAUSSIAN *****

if(Fold==1);

    FWHM=input(' Please enter the FWHM of the Gaussian in ns: ');
    disp(' ')

    Half_FWHM = FWHM / 2.0;
    FWHM = FWHM/10.0; % Converting to Shakes
    digitres=input(' Enter digitizer resolution in (ns): ');
```

```

disp(' ')

widths=input(' Please enter the number of Half-Widths Per Side: ');
disp(' ')

Sigma = FWHM /(realsqrt(8 * log(2)));
disp([' Sigma = ', num2str(Sigma)]);
disp(' ')

% Sigma = 0.318495675;

% Integral = 0.399175132;

start = Half_FWHM * widths;
disp([' start = ', num2str(start)]);
disp(' ')

begin = start * 10.0;
begin = floor(begin);
begin = begin/100.0;

disp([' begin = ', num2str(begin)]);
disp(' ')

finish = abs(begin);
disp([' finish = ', num2str(finish)]);
disp(' ')

Half = (start)/digitres;
disp([' Half = ', num2str(Half)]);
disp(' ')

digitres=digitres/10.0; % Conversion from ns to shakes
disp([' digitres in shakes = ', num2str(digitres)]);
disp(' ')

one_side = Half * 2.0;
disp([' one_side = ', num2str(one_side)]);
disp(' ')

one_side = floor(one_side);
disp([' one_side rounded down = ', num2str(one_side)]);
disp(' ')

width = one_side + 1; % Width of Gaussian
disp([' width = ', num2str(width)]);
disp(' ')

Gaussian=zeros(width,1); % Loads Gaussian with zeros

SumGaussian = zeros(1,1);

% k=0;
l=0;

```

```

j=1;

% disp(' nargin = ', int2str(nargin));

% ***** CALCULATING THE GAUSSIAN *****
for i = -begin:digitres:finish;

    % disp([' i = ', num2str(i)]);

    Gaussian(j,1) = exp(-((i .^ 2)/(2 * (Sigma .^ 2))));

    % disp([' Gaussian(', int2str(j),',1)', ' = ',
num2str(Gaussian(j,1))]);

    SumGaussian(1,1) = (Gaussian(j,1) + SumGaussian(1,1));

    % disp([' SumGaussian = ', num2str(SumGaussian(1,1))]);

    j = j + 1;

end
% ***** SUMMING THE GAUSSIAN *****
% ***** TO CALCULATE THE INTEGRAL *****
SumGaussian(1,1) = SumGaussian(1,1) * 0.02;

disp(' ');
disp([' SumGaussian = ', num2str(SumGaussian(1,1))]);
disp(' ');

% ***** LOADING THE LARGE ARRAY *****
k = 1;
maxcol = nrow + width;

disp([' maxcol = ', int2str(maxcol)]);

NewGaussian = zeros(nrow,maxcol);

for n = 1:nrow;

    Constant = zzz(n,2)/SumGaussian(1,1);

    % disp([' Constant = ', num2str(Constant)]);

    for m = 1:width;

        NewGaussian(n,m) = Constant * Gaussian(m,1);

    % disp(' ');
    % disp([' NewGaussian(',int2str(n) ', ' int2str(m),') =
    ',num2str(NewGaussian(n,m))]);
    % disp(' ');

```

```

        end

    end
    NewGaussianFinal = zeros(nrow,maxcol);
    p = width;
% ***** SHIFTING DATA IN ROWS *****
    for i = 2:nrow;

        for j = p:-1:1;

            % disp([' j = ', int2str(j)]);
            NewGaussianFinal(i,i-1+j) = NewGaussian(i,j);

            % NewGaussian(i,j+1) = NewGaussian(i,j);

% disp([' NewGaussianFinal(', int2str(i), ', ',int2str(i-1+j), ') = ',
num2str(NewGaussianFinal(i,i-1+j))]);

        end

    end

    maxcol = nrow + width;
    NewSum = zeros(1,maxcol);

% ***** SUMMING COLUMNS IN NEWGAUSSIAN *****
    for p = 1:maxcol;

        for q = 1:nrow;

            NewSum(1,p) = NewGaussianFinal(q,p) + NewSum(1,p);
            % disp([' NewSum(1,',int2str(p),') = ', num2str(NewSum(1,p))]);
            end

% disp([' NewSum(1,',int2str(p),') = ', num2str(NewSum(1,p))]);

        end

        lightout=zeros(maxcol,1);
        timeout=zeros(maxcol,1);
        timelight=zeros(maxcol,2);

        for j=1:nrow
            timelight(j,1) = zzz(j,1);
            timeout(j,1) = zzz(j,1);

% disp([' timeout(', int2str(j), ', 1) = ', num2str(timeout(j,1))]);
        end
        disp(' ***** ');
        for j=1:maxcol;
            timelight(j,2) = NewSum(1,j);
            lightout(j,1) = NewSum(1,j);

```

```

    % disp([' lightout(', int2str(j), ', 1) = ',
num2str(lightout(j,1))]);
end
%
Integral=zeros(1,1);
for i=1:maxcol;
%
    Integral(1,1) = (lightout(i,1) + Integral(1,1));
    % disp([' Integral = ', num2str(Integral(1,1))]);
end

disp([' Integral = ', num2str(Integral(1,1))]);

plottools('on', 'figurepalette')
%
% PLOTS LIGHT OUTPUT VS TIME:
%
plot(timeout,lightout)

xlabel('Time (shakes)');
ylabel('Light Output (MeVee)');
xlim([tmin tmax]); % FOR BOTTOM nTOF, STARTING AT 30 SHAKES IS FINE

% ***** FOLDING IN ACTUAL TIME RESPONSE
% *****

elseif(Fold==2);

    Detector_TRF=input(' Please enter the Detector Time Response File:
', 's');
    disp(' ')

    digitres=input(' Enter digitizer resolution in (ns): ');
    disp(' ')

    digitres=digitres/10.0; % Conversion from ns to shakes
    disp([' digitres in shakes = ', num2str(digitres)]);
    disp(' ')

    format loose
    format short
    disp(' *****')
    disp(' ')
    zzz=load(filen); % load data file
    %
    % nrow gets # of rows in data file
    % ncol gets # of columns in data file
    %
    [nrow,ncol]=size(zzz);

    xxx=load(Detector_TRF); % Loads Detector Time Response File
    [width,col]=size(xxx); % width is number of rows in Detector_TRF

    disp([' nrow = ', int2str(nrow)]);
    disp(' ')

```

```

disp([' width = ', int2str(width)]);

SumGaussian = zeros(1,1);

% k=0;
l=0;
j=1;

for i = 1:width;

    SumGaussian(1,1) = (xxx(i,2) + SumGaussian(1,1));

end
% ***** SUMMING THE GAUSSIAN *****
% ***** TO CALCULATE THE INTEGRAL *****
SumGaussian(1,1) = SumGaussian(1,1) * digitres;

disp(' ');
disp([' SumGaussian = ', num2str(SumGaussian(1,1), '%12.7f\n')]);
disp(' ');

% ***** LOADING THE LARGE ARRAY *****
k = 1;
maxcol = nrow + width;

disp([' maxcol = ', int2str(maxcol)]);

NewGaussian = zeros(nrow,maxcol);

for n = 1:nrow;

    Constant = zzz(n,2)/SumGaussian(1,1);

    % disp([' Constant = ', num2str(Constant, '%12.7f\n')]);
    % disp(' ')

    Constant = Constant * 1.0E04;

    % disp([' Constant = ', num2str(Constant, '%12.7f\n')]);
    % disp(' ')

    Constant = round(Constant);

    % disp([' Constant = ', num2str(Constant, '%12.7f\n')]);
    % disp(' ')

    Constant = Constant/1.0E04;

    % disp([' Constant = ', num2str(Constant, '%12.7f\n')]);

    for m = 1:width;

```

```

        NewGaussian(n,m) = Constant * xxx(m,2);

% disp(' ');
% disp([' NewGaussian(',int2str(n) ', ' int2str(m),') = ',num2str(NewGaussian(n,m))]);
% disp(' ');

    end

end

NewGaussianFinal = zeros(nrow,maxcol);
p = width;
% ***** SHIFTING DATA IN ROWS *****
for i = 2:nrow;

    for j = p:-1:1;

        % disp([' j = ', int2str(j)]);
        NewGaussianFinal(i,i-1+j) = NewGaussian(i,j);

        NewGaussian(i,j+1) = NewGaussian(i,j);

% disp([' NewGaussianFinal(', int2str(i), ', ',int2str(i-1+j),') = ',
num2str(NewGaussianFinal(i,i-1+j))]);

    end

end

maxcol = nrow + width;
NewSum = zeros(1,maxcol);

% ***** SUMMING COLUMNS IN NEWGAUSSIAN *****
for p = 1:maxcol;

    for q = 1:nrow;

        NewSum(1,p) = NewGaussianFinal(q,p) + NewSum(1,p);
        % disp([' NewSum(1,',int2str(p),') = ', num2str(NewSum(1,p))]);
    end

% disp([' NewSum(1,',int2str(p),') = ', num2str(NewSum(1,p))]);

end

lightout=zeros(maxcol,1);
timeout=zeros(maxcol,1);
timelight=zeros(maxcol,2);

for j=1:nrow
    timelight(j,1) = zzz(j,1);
    timeout(j,1) = zzz(j,1);
end

```

```

% disp([' timeout(', int2str(j),', 1) = ', num2str(timeout(j,1))]);
end

disp(' ***** ');

for j=1:maxcol;
    timelight(j,2) = NewSum(1,j);
    lightout(j,1) = NewSum(1,j);

    % disp([' lightout(', int2str(j),', 1) = ',
num2str(lightout(j,1))]);
end
%
Integral=zeros(1,1);
for i=1:maxcol;
%
    Integral(1,1) = (lightout(i,1) + Integral(1,1));
    % disp([' Integral = ', num2str(Integral(1,1))]);
end

disp([' Integral = ', num2str(Integral(1,1))]);

plottools('on', 'figurepalette')
%
% PLOTS LIGHT OUTPUT VS TIME:
%
plot(timeout,lightout)

xlabel('Time (shakes)');
ylabel('Light Output (MeVee)');
xlim([tmin tmax]); % FOR BOTTOM nTOF, STARTING AT 30 SHAKES IS FINE

end

if writefile==1
%
    ind1=find(fileout=='.'); % If '.' in filename, ind1=# of
characters
%                                up to '.'
    if ind1
        root=fileout(1:ind1-1); % root=filename w/o '.'
    else
        root=fileout;           % elseif no '.', root=filename
    end
%
    dlmwrite(root, timelight); % Writes matrix timelight into ASCII format
%                               file using default delimiter ',' to
%                               separate matrix elements; starting at the
%                               first column and first row of filename.
%                               ASCII file takes the name of root (the
%                               filename input at the beginning)

end

disp(' ')

```

```
disp(' Got to here -- end of program')
%
disp(' ')
toc % ends the stopwatch timer
disp(' ')
%
return
```

APPENDIX D

THE DECONVOLUTION ("UNFOLDING") CODE

```

PROGRAM deconvlv
!C  driver for routine convlv
INTEGER N,N2,M
REAL PI
!C
PARAMETER (N = 2048, M = 2046, N2 = 4096, pi = 3.14159265, NMAX=4096)
INTEGER i, ISIGN
DIMENSION DATA(N),RESPNS(M),RESP(N),ANS(N2),FOLD(N),TIME(N)
REAL Time1, Amp1, Time2, Amp2
REAL RESPNST(N)

CHARACTER*80 FNAME
CHARACTER*80 FNAMER

ISIGN = -1

!C  INPUT THE FOLDED IN FILE NAME ON THE TERMINAL
!C
WRITE (*,2)
2  FORMAT ()
WRITE (*,*) ' ENTER FOLDED IN FILE NAME OF DETECTOR DATA: '
READ (*,'(A)') FNAME
OPEN(UNIT=3,FILE=FNAME,STATUS='OLD')

OPEN(UNIT = 8, FILE = 'Unfold_Output') ! Open Output File

!C  READ IN DATA (TIME IN SHAKES AND AMPLITUDE):

DO i=1,N

READ(3,10,END=20) Time1, Amp1 ! THIS READS THE FOLDED-IN DETECTOR
                              ! FILE OF ANY LENGTH AND STORES THE
10  FORMAT(F7.4, 1x, F11.6)    ! VALUES IN AN ARRAY "FOLD";
                              ! F8.4,T16,F14.8

TIME (i) = Time1
FOLD (i) = Amp1
DATA(i) = Amp1

WRITE(*,12) i, Amp1
12  FORMAT('FOLD(1,',i6,') = ', 3x, F11.6)
WRITE(*,13) i, Time1
13  FORMAT('TIME(1,',i6,') = ', 3x, F7.4)

END DO

20  ENDFILE(UNIT=3)

! *****

WRITE(8,21) FNAME
21  FORMAT(A)

```

```

        DO i = 1, N

            WRITE(8,22) TIME(i), FOLD(i)

22        FORMAT(F7.4, 3x, F11.9)

        END DO

! *****

!C  INPUT THE RESPONSE FUNCTION OF THE DETECTOR

        WRITE(*,23)
23        FORMAT()
        WRITE (*,*) ' ENTER RESPONSE FUNCTION OF DETECTOR: '
        READ (*,'(A)') FNAMER

        OPEN(UNIT=7,FILE=FNAMER,STATUS='OLD')

        DO i=1,M

            READ(7,30,END=40) Time2, Amp2

30        FORMAT(F6.3, T8, F9.6)

            RESPNST(i) = Time2
            RESPNS(i) = Amp2
            RESP(i) = Amp2

            WRITE(*,31) i, Time2
31        FORMAT(' Time2(1,',i4,') = ', 3x, F6.3)

            WRITE(*,32) i, Amp2
32        FORMAT(' Amp2(1,',i4,') = ', 3x, F9.4)

        END DO

40        ENDFILE(UNIT=7)

! *****

        WRITE(8,41)
41        FORMAT()

        WRITE(8,42) FNAMER
42        FORMAT(A)

        DO i = 1, M

            WRITE(8,43) RESPNST(i), RESPNS(i)

43        FORMAT(F6.3, 3x, F8.6)

        END DO

        call convlv(DATA,N,RESP,M,ISIGN,ANS)
! ***** PRINT ANSWER OUT HERE *****
! *****
        WRITE(8,44)

```

```

44  FORMAT( )

WRITE(8,45) ' PROGRAM UNFOLD RESULTS: '
45  FORMAT(A)

DO i = 1, N

    WRITE(8,46) TIME(i), ANS(i)

46    FORMAT(3X,F10.6, 3X, F13.6, 3X, F13.6)

END DO

WRITE(*,47)
47  FORMAT( )

WRITE(*,48) ' PROGRAM UNFOLD RESULTS: '
48  FORMAT(A)

DO i = 1, N

    WRITE(*,49) TIME(i), ANS(i)

49    FORMAT(3X,F10.6, 3X,F13.6, 3X, E13.6)

END DO

END

SUBROUTINE convlv(data,n, respns,m, isign, ans)
INTEGER isign,m,n,NMAX
REAL data(n), respns(n)
COMPLEX ans(n)
PARAMETER (NMAX=4096)
CU  USES realft,twofft
INTEGER i,no2
COMPLEX fft(NMAX)
do 11 i=1,(m-1)/2
    respns(n+1-i)=respns(m+1-i)
11  continue
do 12 i=(m+3)/2,n-(m-1)/2
    respns(i)=0.0
12  continue
call twofft(data, respns, fft, ans,n)
no2=n/2
do 13 i=1,no2+1
    if (isign.eq.1) then
        ans(i)=fft(i)*ans(i)/no2
    else if (isign.eq.-1) then
        if (abs(ans(i)).eq.0.0) pause
        *'deconvolving at response zero in convlv'
        ans(i)=fft(i)/ans(i)/no2
    else
        pause 'no meaning for isign in convlv'
    endif
13  continue
ans(1)=cmplx(real(ans(1)),real(ans(no2+1)))
call realft(ans,n,-1)
return
END

```

```

SUBROUTINE four1(data,nn, isign)
INTEGER isign,nn
REAL data(2*nn)
INTEGER i, istep, j, m, mmax, n
REAL tempi, tempr
DOUBLE PRECISION theta, wi, wpi, wpr, wr, wtemp
n=2*nn
j=1
do 11 i=1, n, 2
    if(j.gt.i)then
        tempr=data(j)
        tempi=data(j+1)
        data(j)=data(i)
        data(j+1)=data(i+1)
        data(i)=tempr
        data(i+1)=tempi
    endif
    m=nn
1   if ((m.ge.2).and.(j.gt.m)) then
        j=j-m
        m=m/2
        goto 1
    endif
    j=j+m
11  continue
    mmax=2
2   if (n.gt.mmax) then
        istep=2*mmax
        theta=6.28318530717959d0/(isign*mmax)
        wpr=-2.d0*sin(0.5d0*theta)**2
        wpi=sin(theta)
        wr=1.d0
        wi=0.d0
        do 13 m=1, mmax, 2
            do 12 i=m, n, istep
                j=i+mmax
                tempr=sngl(wr)*data(j)-sngl(wi)*data(j+1)
                tempi=sngl(wr)*data(j+1)+sngl(wi)*data(j)
                data(j)=data(i)-tempr
                data(j+1)=data(i+1)-tempi
                data(i)=data(i)+tempr
                data(i+1)=data(i+1)+tempi
12             continue
                wtemp=wr
                wr=wr*wpr-wi*wpi+wr
                wi=wi*wpr+wtemp*wpi+wi
13            continue
                mmax=istep
            goto 2
        endif
        return
    END

SUBROUTINE realft(data, n, isign)
INTEGER isign, n
REAL data(n)

```

```

CU      USES four1
      INTEGER i, i1, i2, i3, i4, n2p3
      REAL c1, c2, h1i, h1r, h2i, h2r, wis, wrs
      DOUBLE PRECISION theta, wi, wpi, wpr, wr, wtemp
      theta=3.141592653589793d0/dble(n/2)
      c1=0.5
      if (isign.eq.1) then
        c2=-0.5
        call four1(data, n/2, +1)
      else
        c2=0.5
        theta=-theta
      endif
      wpr=-2.0d0*sin(0.5d0*theta)**2
      wpi=sin(theta)
      wr=1.0d0+wpr
      wi=wpi
      n2p3=n+3
      do 11 i=2, n/4
        i1=2*i-1
        i2=i1+1
        i3=n2p3-i2
        i4=i3+1
        wrs=sngl(wr)
        wis=sngl(wi)
        h1r=c1*(data(i1)+data(i3))
        h1i=c1*(data(i2)-data(i4))
        h2r=-c2*(data(i2)+data(i4))
        h2i=c2*(data(i1)-data(i3))
        data(i1)=h1r+wrs*h2r-wis*h2i
        data(i2)=h1i+wrs*h2i+wis*h2r
        data(i3)=h1r-wrs*h2r+wis*h2i
        data(i4)=-h1i+wrs*h2i+wis*h2r
        wtemp=wr
        wr=wr*wpr-wi*wpi+wr
        wi=wi*wpr+wtemp*wpi+wi
11      continue
      if (isign.eq.1) then
        h1r=data(1)
        data(1)=h1r+data(2)
        data(2)=h1r-data(2)
      else
        h1r=data(1)
        data(1)=c1*(h1r+data(2))
        data(2)=c1*(h1r-data(2))
        call four1(data, n/2, -1)
      endif
      return
      END

      SUBROUTINE twoffft(data1, data2, fft1, fft2, n)
      INTEGER n
      REAL data1(n), data2(n)
      COMPLEX fft1(n), fft2(n)
CU      USES four1
      INTEGER j, n2
      COMPLEX h1, h2, c1, c2

```

```

c1=cmplx(0.5,0.0)
c2=cmplx(0.0,-0.5)
do 11 j=1,n
  fft1(j)=cmplx(data1(j),data2(j))
11 continue
call four1(fft1,n,1)
fft2(1)=cmplx(aimag(fft1(1)),0.0)
fft1(1)=cmplx(real(fft1(1)),0.0)
n2=n+2
do 12 j=2,n/2+1
  h1=c1*(fft1(j)+conjg(fft1(n2-j)))
  h2=c2*(fft1(j)-conjg(fft1(n2-j)))
  fft1(j)=h1
  fft1(n2-j)=conjg(h1)
  fft2(j)=h2
  fft2(n2-j)=conjg(h2)
12 continue
return
END

```

APPENDIX E

IDAHO ACCELERATOR CENTER LAYOUT

Shown in Figure 47 is the layout of the experiments that were performed at the Idaho Accelerator Center located at Idaho State University in Pocatello, Idaho [24]. The goal was to measure the time response of nTOF detectors using 50 ps pulses of x-rays. Initially the nTOFs were placed in the “Great Hall” which housed the 15 MeV linac itself but the data had a high degree of background due to scattering, therefore the nTOFs were moved into the “Shielded Cell” – a room separated from the Great Hall by two 30.48 cm (1 ft) thick concrete walls separated by 1.2192 m (4 ft) of earth, through which

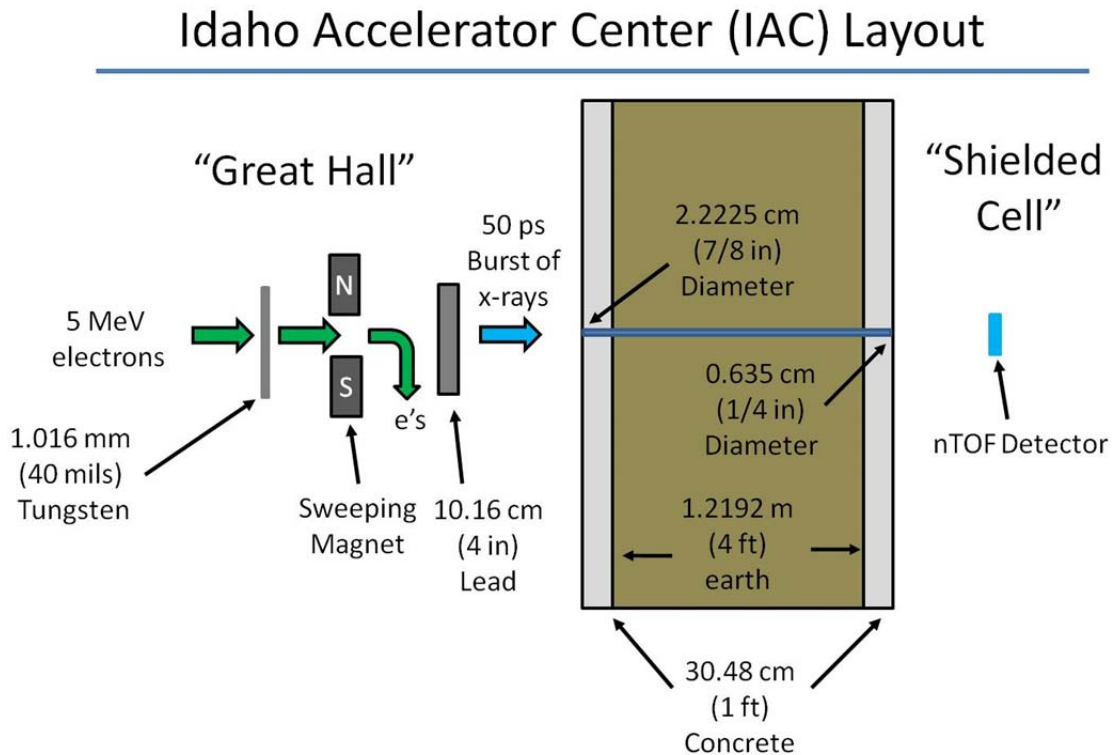


Figure 47. Idaho Accelerator Center (IAC) Layout. The “Great Hall” housed the 15 MeV Linac. The nTOF detectors were placed in the “Shielded Cell” behind two 30.48 cm (1 ft) thick walls separated by 1.292 m (4 ft) of earth. The entrance aperture in the Great Hall was 2.2225 cm (7/8 in) diameter and the exit aperture in the Shielded Cell was 0.635 cm (1/4 in). This geometry provided good data with very little background. The goal was to measure the time response of the detectors using 50 ps bursts of x-rays.

a narrow collimator ran from the Great Hall into the Shielded Cell. The entrance aperture of the collimator was 2.2225 cm (7/8 in) and the exit aperture was 0.635 cm (1/4 in). The data obtained from the nTOFs placed in the Shielded Cell was quite good, and shown in Figure 48.

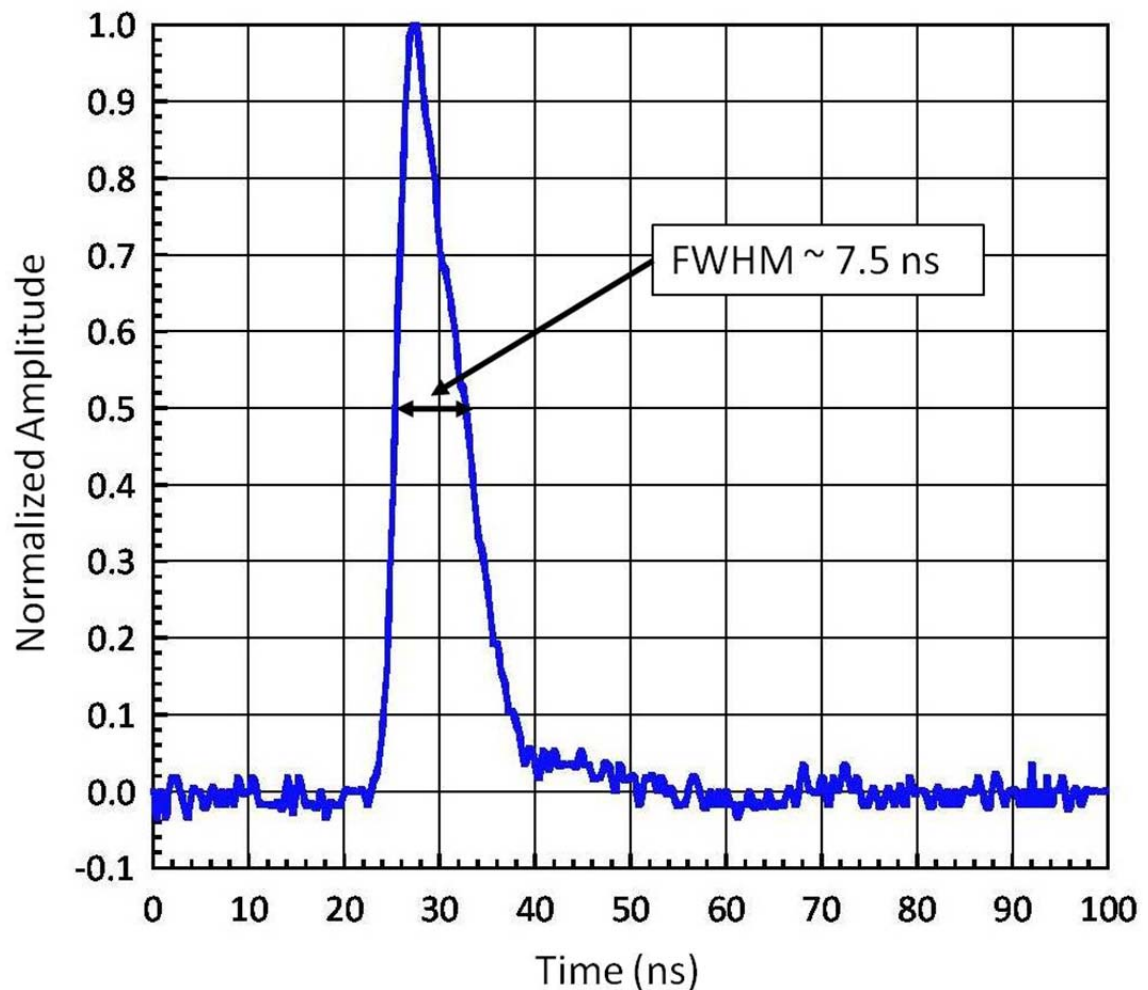


Figure 48. Experimental Time response found at the Idaho Accelerator Center (IAC) using 50 ps bursts of x-rays. The full width at half maxima is approximately 7.5 ns. This data was obtained in the “Shielded Cell” (see Figure 47) where the background was quite low due to the extensive amount of shielding and narrow collimation.

It was found that the best results were obtained when the linac operated at 400 mA, and pulsed 5 MeV electrons into 1.016 mm (40 mils) of tungsten. A sweeping

magnet removed the electrons out of the beam, leaving only the 50 ps bursts of x-rays which were attenuated by 10.16 cm (4 in) of lead. The x-rays were collimated through two 30.48 cm (1 ft) thick concrete walls and 1.2192 m (4 ft) of earth, then entered the shielded cell. The data was recorded on a Tektronix TDS7254B 2.5 GHz, 4 channel digital phosphor digitizer [19] in an average over several pulses (typically 32). In this way, the time response of four nTOF detectors was found with a nominal value of a full width at half maxima to be 7.5 ns.

APPENDIX F

NEW COLLIMATOR DESIGN

In the 2006 – 2007 timeframe, the Z-Machine was refurbished, and attention was paid to upgrading all diagnostics. It was known that the addition of the collimator under target chamber center greatly improved neutron signals as shown in this work; however, there was room for improvement. Therefore, a design of a new collimator was undertaken, to have a great deal more mass than the first one. Figure 49 shows the model of the first collimator that was shown to improve signals on shot z1549.

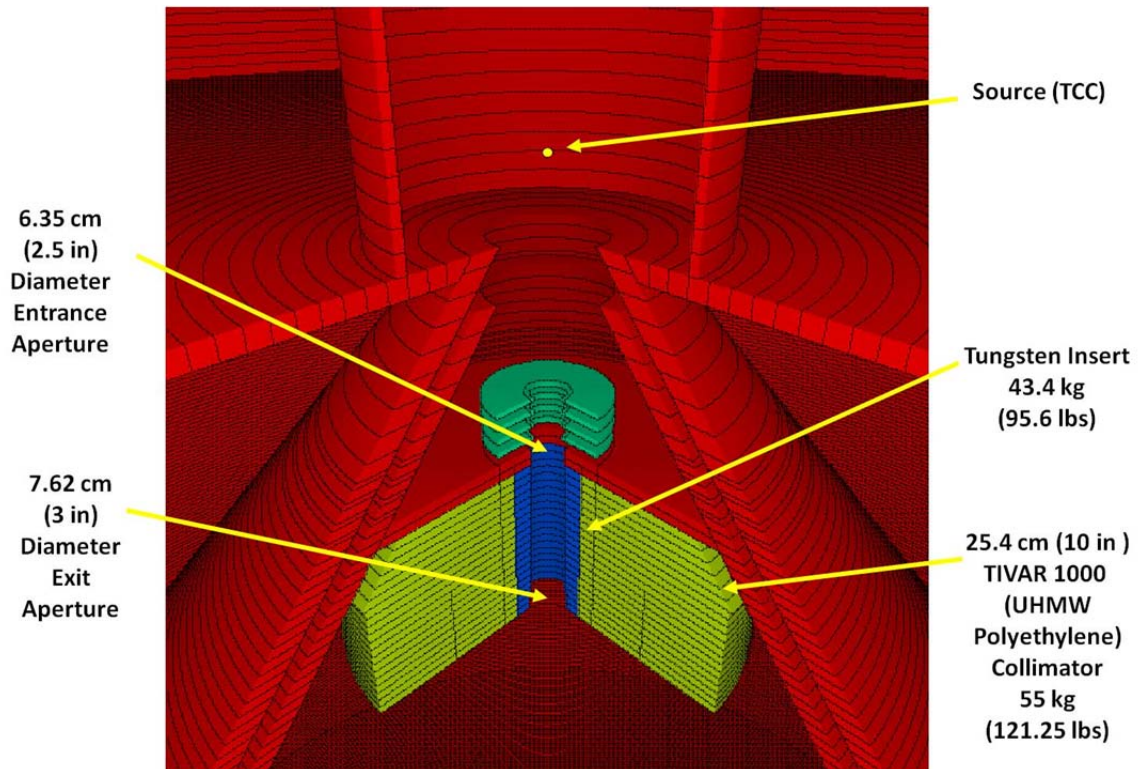


Figure 49. The model of the first neutron collimator used on the Z-machine. It was 30.48 cm (12 in) in radius and 25.4 cm (10 in) tall, made out of ultra-high molecular weight polyethylene (TIVAR 1000) [27]. It had a entrance aperture of 6.35 cm (2.5 in), and an exit aperture of 7.62 cm (3 in). It weighed 55 kg (121.25 lbs); the tungsten insert weighed 43.4 kg (95.6 lbs). It was installed on the machine in sections.

Figure 50 shows the design of the new collimator. The radius was increased – the top radius is 24.75 cm (9.74 in) and the bottom radius is 45 cm (17.7 in). Also, a cylinder of ultra-high molecular weight polyethylene (TIVAR 1000) [27] 38.1 cm (15 in) was added along the axis, giving it a mushroom appearance. The aperture along the Z-axis was 3.81 cm (1.5 in) in diameter (note that this is half the diameter of the previous collimator’s exit aperture, or 7.62 cm (3 in)). The mass of the new collimator was 109.5 kg (241.3 lbs), and the mass of the tungsten insert was 8.3 kg (18.4 lbs). Since the

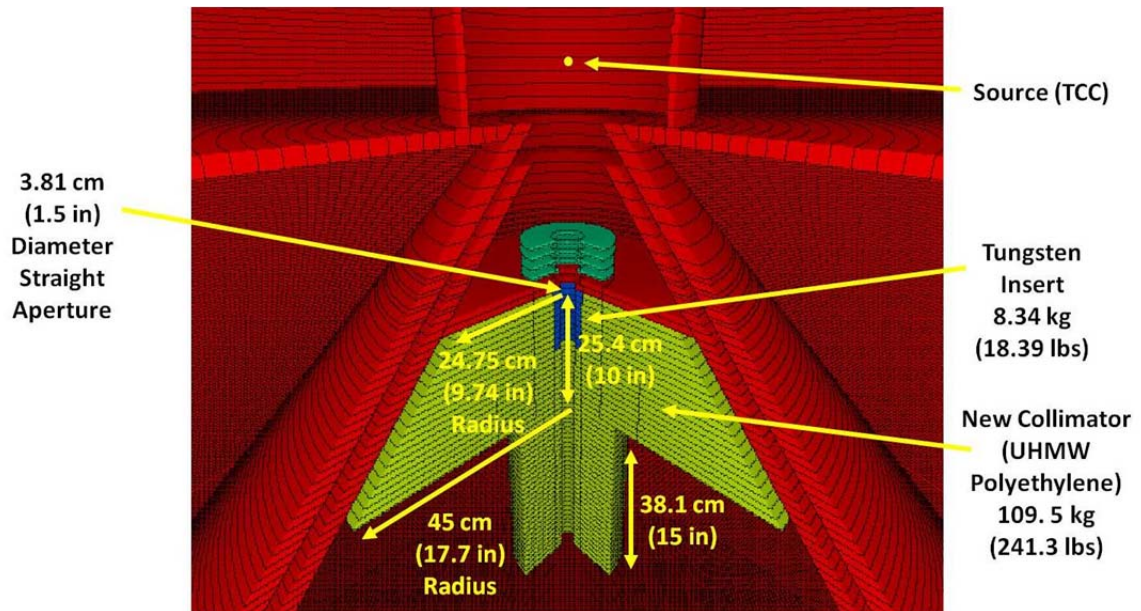


Figure 50. The new collimator design. The top radius is 24.75 cm (9.74 in) and the bottom radius is 45 cm (17.7 in). A cylinder of ultra-high molecular weight polyethylene (TIVAR 1000) [27] was added along the axis, giving it a mushroom appearance. The aperture along the Z-axis was 3.81 cm (1.5 in) in diameter and did not taper. The mass of the collimator was 109.5 kg (241.3 lbs), and the mass of the tungsten insert was 8.3 kg (18.4 lbs). Since the collimator had to be installed on the machine by hand by the center section, it was installed in sections due to its massive weight.

collimator had to be installed on the machine by hand by the center section, it was installed in sections due to its massive weight.

The model with the old collimator (Figure 49) is shown in Figure 51 for the bottom nTOF (location “D” in Figure 1). Of note is the additional, second scattering peak that occurs later in time, at about 460 ns.

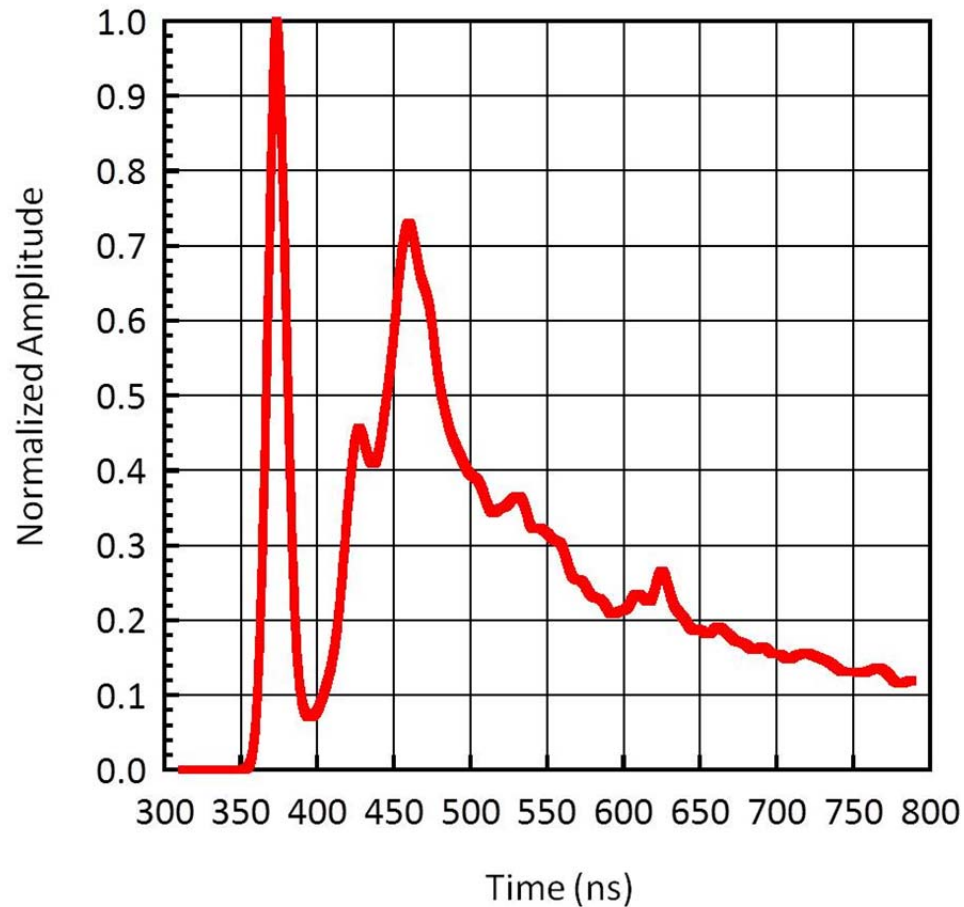


Figure 51. The model with the old collimator (Figure 49) for the bottom nTOF (location “D” in Figure 1). Despite the fact that the addition of the old collimator improved the signal, there is still a second scattering peak which occurs later in time at about 460 ns.

The model with the new collimator (Figure 50) is shown in Figure 52 for the bottom nTOF (location “D” in Figure 1). Note that the second scattering peak in Figure 51 goes away, leaving a very clean neutron signal.

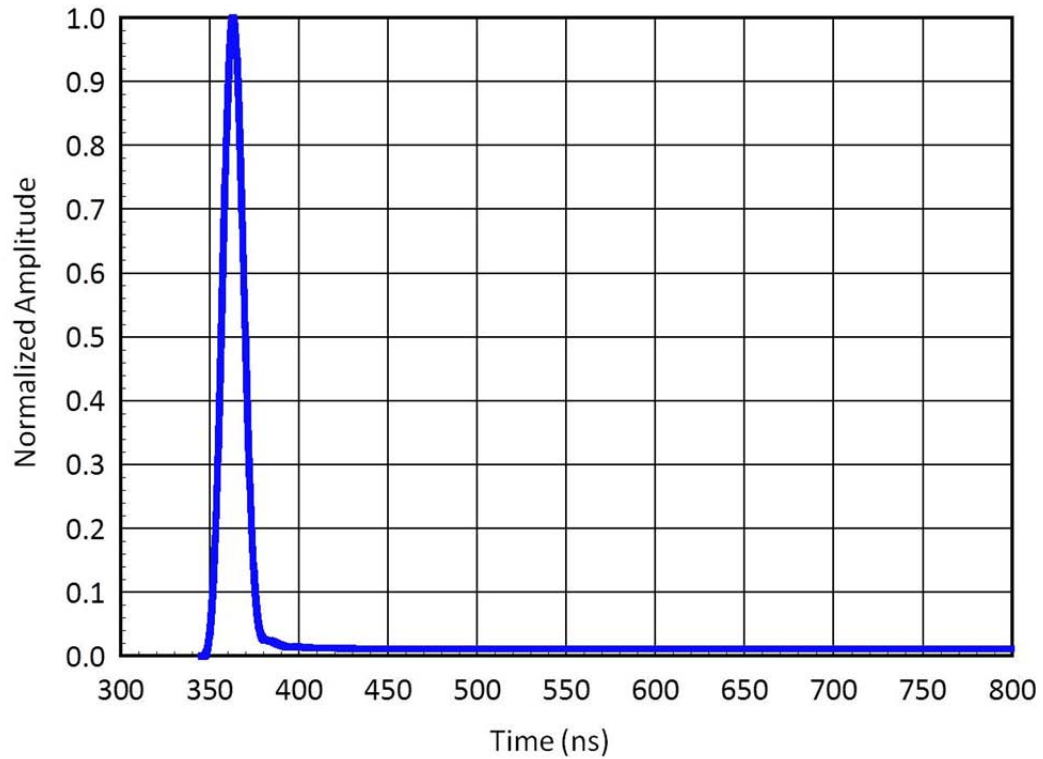


Figure 52. The model with the new collimator (Figure 50) for the bottom nTOF (location “D” in Figure 1). Note that the second scattering peak shown in Figure 51 has gone away, leaving a very clean neutron signal.

Figure 53 shows the model of the old collimator (Figure 49) for the top nTOF (location “C” in Figure 1). Although the old collimator did improve the signal, there is still some scattering later in time, past the primary neutron peak. Figure 54 shows the model of the new collimator (Figure 50) for the top nTOF (location “C” in Figure 1). Note that the scattering later in time is greatly reduced, showing that the additional mass of the new collimator was necessary to improve the neutron signal.

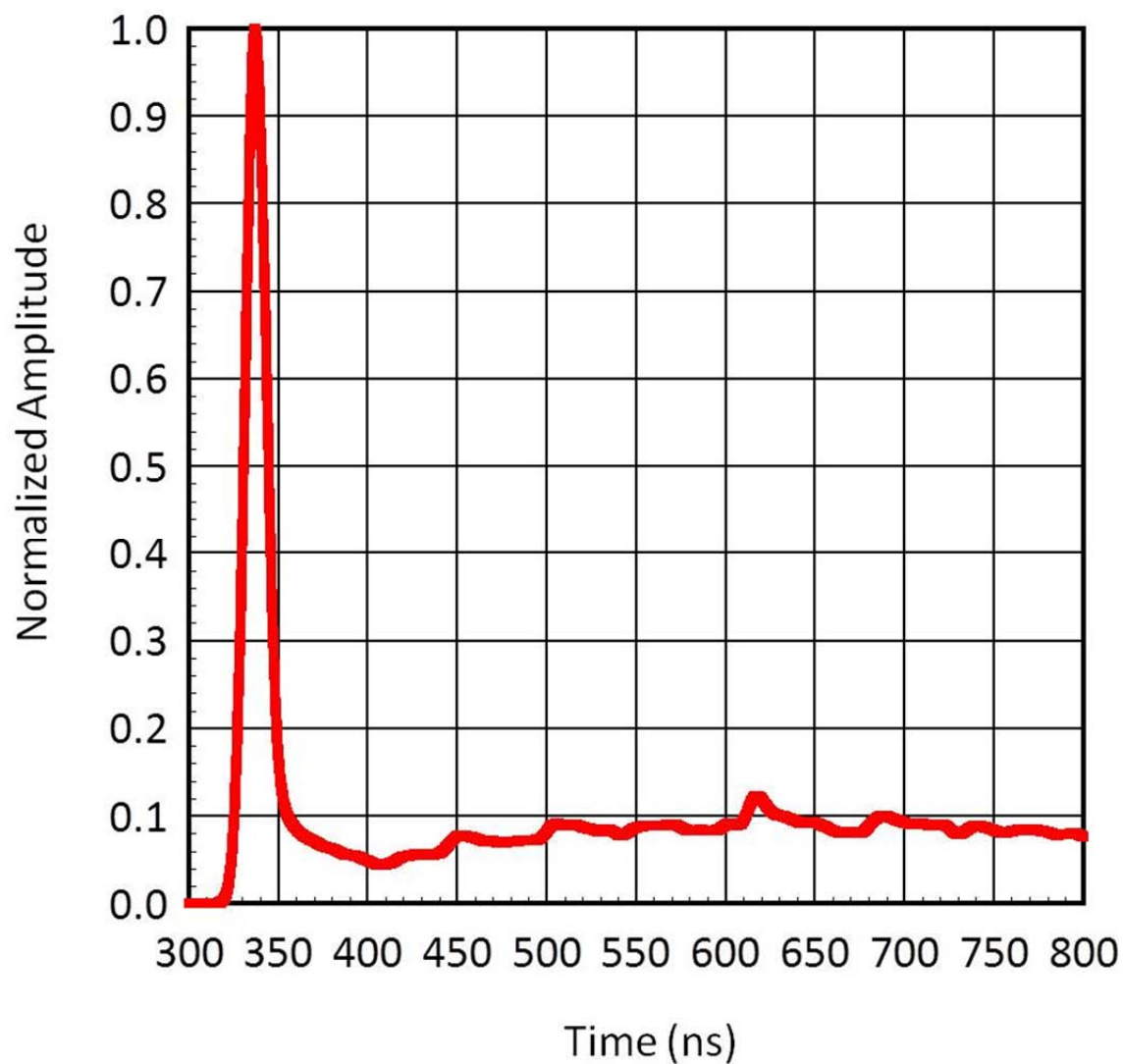


Figure 53. The model of the old collimator (Figure 49) for the top nTOF (location “C” in Figure 1). Although the addition of the old collimator did improve the signal, there is still scattering later in time past the primary neutron peak.

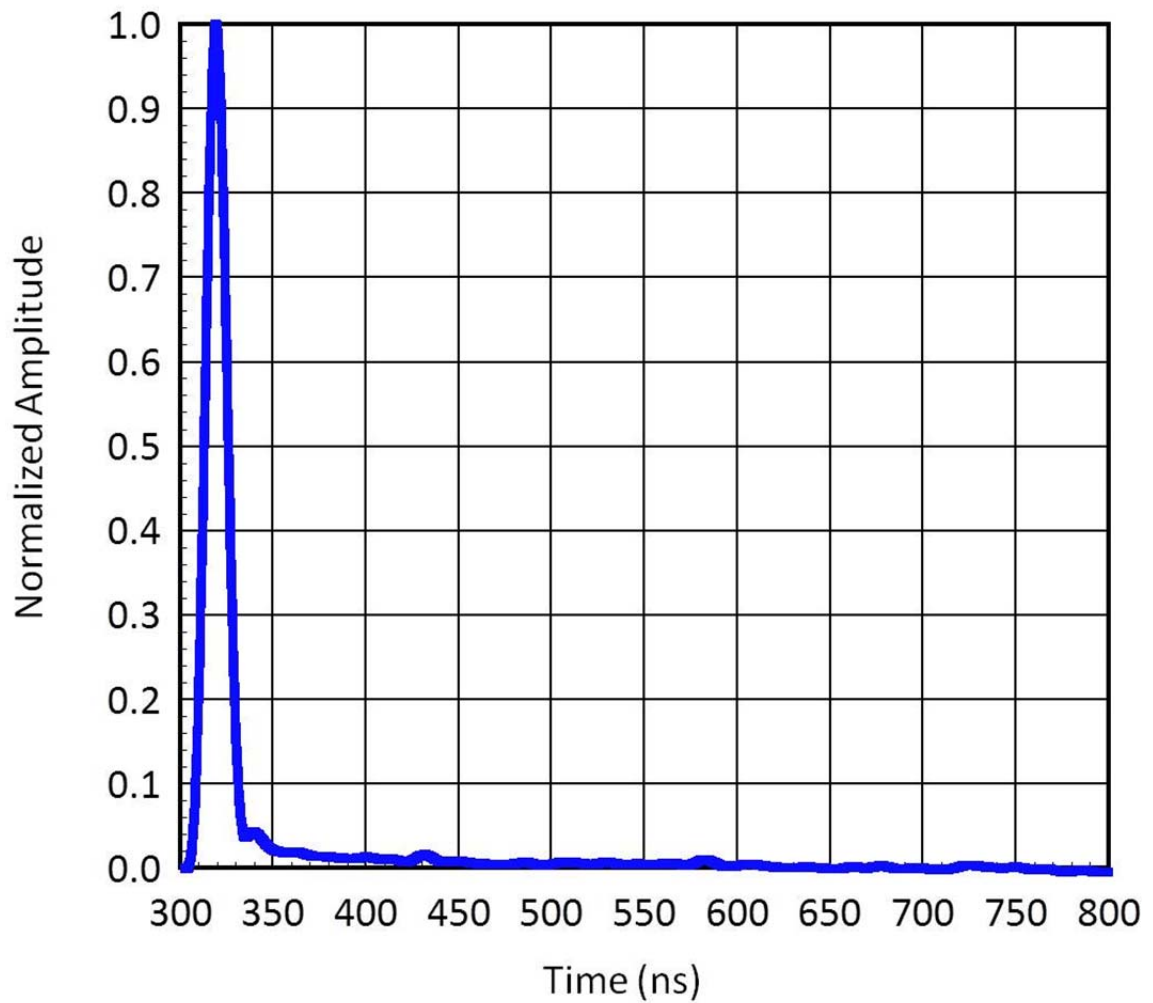


Figure 54. The model with the new collimator for the top nTOF (location “C” in Figure 1). Note that the scattering later in time is greatly reduced, showing that the additional mass of the new collimator was necessary to improve the neutron signal.

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