A novel method for modeling the neutron Time of Flight (nTOF) detector response in current mode to inertial confinement fusion experiments

Alan Nelson

Follow this and additional works at: http://digitalrepository.unm.edu/ne_etds

Recommended Citation
Alan John Nelson

Candidate

Department of Chemical and Nuclear Engineering

Department

This dissertation is approved, and it is acceptable in quality and form for publication:

Approved by the Dissertation Committee:

Dr. Gary Cooper, Chairperson

Dr. Carlos Ruiz

Dr. Anil Prinja

Dr. Mark Gilmore
A NOVEL METHOD FOR MODELING THE NEUTRON TIME OF FLIGHT (nTOF) DETECTOR RESPONSE IN CURRENT MODE TO INERTIAL CONFINEMENT FUSION EXPERIMENTS

By

ALAN JOHN NELSON

B.S. NUCLEAR ENGINEERING
THE UNIVERSITY OF NEW MEXICO, 1988
M.S. NUCLEAR ENGINEERING
THE UNIVERSITY OF NEW MEXICO, 2003

DISSERTATION
Submitted in Partial Fulfillment of the Requirements of the Degree of
Doctor of Philosophy
Engineering

The University of New Mexico
Albuquerque, New Mexico

December, 2011
DEDICATION

To Kathleen, the love of my life.

And to my family. To my mother Joyce and father Henry, to Uncle Lou and Iyay (Aunt Alice), and to my brothers Eric, Jay and Tim, to my sister Rosie and her husband Bill, to my nephew Robby (son of Hip) and his mother Ann. To my nephews on the west coast, Zack, his wife Cyndy and their son Sam, and Ike (sons of Eric), their stepsister Molly and her mother Caren. And especially to my identical twin brother Lou.

I would like to thank them all for their support and encouragement.

And finally, to all MCNP users everywhere who have ever tried to read – and understand – an MCNP manual. Believe me, I feel your pain.

Umpiyeo!!
ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Gary Cooper, my faculty advisor, and Dr. Carlos Ruiz of Sandia National Laboratories (PMTS), for their never-ending patience and unwavering support and encouragement during the course of this work. I would also like to thank Carlos for all our countless conversations where he “set me straight” on a myriad of topics. I would also like to thank Dr. Ray Leeper for his steadfast support. In addition, I would like to acknowledge Sandia National Laboratories, and in particular, Dr. Keith Matzen and Dr. John Porter for providing funding for this work. Also, special thanks go to Dr. Gordon Chandler, Dr. Kelly Hahn, and technologists José Torres and Ruth Smelser for providing support and encouragement. Great thanks goes out to Dr. Dave Fehl for all his assistance as well.

And finally, I would like to thank Brent Davis, Irene Garza, Larry Robbins, Dr. Chris Hagen, Dr. Lee Ziegler, Steve Molnar and Tim Meehan of National Security Technologies (NSTec) for not only building the nTOF detectors, but also testing and characterizing them, and providing the support and facilities necessary for calibrating them as well.
A Novel Method for Modeling the Neutron Time of Flight (nTOF) Detector Response in Current Mode to Inertial Confinement Fusion Experiments

By

Alan John Nelson

B.S., Nuclear Engineering, University of New Mexico, 1988

M.S., Nuclear Engineering, University of New Mexico, 2003

Ph.D., Engineering, University of New Mexico, 2011

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\(^1\); the OMEGA Laser Facility at the University of Rochester in Rochester, NY\(^2\); and the National Ignition Facility (NIF) operated by the Department of Energy at Lawrence Livermore National Laboratory in Livermore, California\(^3\). They all incorporate neutron time of flight (nTOF) detectors which measure neutron yield, and the shapes of the waveforms from these detectors contain germane 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

\(^{1}\text{Matzen, K., Phys. Plasmas 4, 1519 (1997).}\)


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\textsuperscript{\textcopyright} 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.
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\(^\phi\) (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.

\(^{8}\)1 MeVee = amount of light produced by 1 MeV deposited by a Compton scattered electron.
TABLE OF CONTENTS

LIST OF FIGURES ................................................................................................................. xi
LIST OF TABLES ................................................................................................................. xvi
CHAPTER 1 INTRODUCTION ............................................................................................... 1
CHAPTER 2 MCNP-PoliMi ................................................................................................... 8
CHAPTER 3 RESPONSE FUNCTIONS ............................................................................. 10
  ENERGY DEPOSITED VS LIGHT OUTPUT ......................................................................... 12
CHAPTER 4 THE POST-PROCESSING CODE .................................................................... 14
CHAPTER 5 VARIANCE REDUCTION ................................................................................ 18
  WEIGHT WINDOWS ........................................................................................................... 18
  POINT/RING DETECTOR ................................................................................................. 19
  DXTRAN .......................................................................................................................... 20
  FORCED COLLISIONS ..................................................................................................... 20
  IMPLICIT CAPTURE ....................................................................................................... 21
  VARIANCE REDUCTION CAVEATS ............................................................................... 22
  SMOOTHING THE RAW SIMULATED DATA .................................................................... 23
CHAPTER 6 CONVOLVING THE TIME RESPONSE ............................................................. 26
  BROADENING DUE TO TEMPERATURE AND TIME RESPONSE ................................. 27
  COMPARING CALCULATIONS WITH EMPIRICAL DATA .............................................. 29
CHAPTER 7 DECONVOLVING THE TIME RESPONSE FROM THE SIMULATED DATA ...... 41
CHAPTER 8 CONVOLVING A NEUTRON IMPULSE RESPONSE WITH THE KNOWN TIME
  RESPONSE ......................................................................................................................... 45
PRIMARY AND SECONDARY NEUTRON SCATTERING............................................................47

CHAPTER 9 DECONVOLVING THE NEUTRON AND TIMING INSTRUMENT RESPONSE OUT
OF THE REAL DATA ......................................................................................................... 53

SUBTRACTING THE CONTRIBUTION DUE TO NEUTRON SCATTERING .......................... 53

CHAPTER 10 MAKING THE TRANSFORMATION FROM \( \frac{dN}{dt} \) to \( \frac{dN}{dE} \) ............. 58

CHAPTER 11 IDENTIFYING SOURCES OF NEUTRON SCATTERING ............................... 71

CHAPTER 12 CONCLUSIONS ......................................................................................... 75

FUTURE WORK .............................................................................................................. 77

APPENDICIES .............................................................................................................. 81

APPENDIX A MCNP-PoliMi INPUT DECK ................................................................. 82

APPENDIX B THE nTOF POST-PROCESSING CODE ................................................. 135

APPENDIX C THE CONVOLUTION ("FOLDING IN") CODE ........................................... 141

APPENDIX D THE DECONVOLUTION ("UNFOLDING") CODE .................................... 150

APPENDIX E IDAHO ACCELERATOR CENTER LAYOUT .............................................. 156

APPENDIX F NEW COLLIMATOR DESIGN .................................................................... 159

REFERENCES ............................................................................................................. 165
LIST OF FIGURES

Figure 1. Schematic of nTOF Detector Positions relative to ICF Capsule .......................... 2
Figure 2. Axial Cross Sectional Diagram of the Z-Facility ................................................... 3
Figure 3. 3-D View near Source (TCC) ................................................................................ 4
Figure 4. Original Basement “Pig” and its MCNP-PoliMi model ........................................ 5
Figure 5. 3-D View of Polyethylene Collimator and Top nTOF .......................................... 6
Figure 6. 3-D View of Top and Bottom nTOF Detectors .................................................... 7
Figure 7. The Nonlinearity of Scintillator Light Output.......................................................... 11
Figure 8. Energy Deposition (MeV) vs Light Output (MeVee) ......................................... 13
Figure 9. Flowchart of the Post-Processing Code ............................................................ 15
Figure 10. An analog MCNP-PoliMi model (i.e., without any Variance Reduction
Techniques applied) ................................................................................................ 17
Figure 11. Output of the Post-Processing code for the largest amount of scattering seen
in an nTOF signal for this type of experiment ................................................................... 24
Figure 12. Smoothing the data with the Savitzky-Golay smoothing filter......................... 25
Figure 13. Detector time response of an nTOF detector found at the Idaho Accelerator
Center (IAC). .................................................................................................................. 26
Figure 14. Broadening due to Temperature and Time Response .................................... 28
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 for a detector located at "D" in Figure 1. ............................................ 30
Figure 16. Close-up of the primary neutron peak in Figure 15, for the bottom nTOF detector located at "D" in Figure 1. .......................................................... 31

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........................................... 32

Figure 18. Close-up of the primary neutron peak in Figure 17, for the top nTOF detector located at "C" in Figure 1…………………………………………………………………………………….33

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 ........................................................................................................................................................................................................................................................................................................... 34

Figure 20. “Shadow” of TIVAR 1000 Collimator............................................................... 35

Figure 21. With the pig aligned 3 degrees off-axis, the collimator “cone” just encompassed both detectors.......................................................................................................................... 36

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 ............................................................................ 37

Figure 23. Close-up of the primary neutron peak in Figure 22, for the bottom nTOF detector located at "D" in Figure 1, with the TIVAR 1000 Collimator in place ...... 38

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.......................................................... 39
Figure 25. Close-up of the primary neutron peak in Figure 21, for the top nTOF detector located at "C" in Figure 1 with the TIVAR 1000 Collimator in place ........................................ 40

Figure 26. Preparation for the signal prior to taking Fast Fourier Transforms .................. 42

Figure 27. "Wrap-Around Order." .................................................................................... 43

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). .............. 44

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 ........................................ 45

Figure 30. The neutron impulse response divided up into its component parts: primary and secondary scattering ....................................................................................... 48

Figure 31. The convolution of the neutron impulse response (Figure 29) with the time response (Figure 13) found at the Idaho Accelerator Center (IAC) ......................... 50

Figure 32. Schematic of the time delays that need to be taken into account from the time a neutron impinges upon the scintillator to the time an output pulse is generated by the photomultiplier tube and base ........................................... 51

Figure 33. The Neutron Impulse/Time Response corrected for the time when radiation first impinges upon the detector ................................................................. 52

Figure 34. The empirical data from z1217 with the neutron impulse and timing information (Figure 31) deconvolved out of it ................................................................. 54

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 ........................................................................................................ 55
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................................................................................................................. 56

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................................................................. 57

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 ................................................ 61

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) to produce the contribution to scattering (green)........................................................................................................................................ 63

Figure 40. Energy Spectra for both the Top and Bottom nTOF detectors at locations “C” and “D” in Figure 1 from shot z1217................................................................................. 65

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)...............................................................................66

Figure 42. The "Ideal Case" (red) -- i.e., a 2.54 cm (1 inch) scintillator placed 730 cm away from a 2 keV DD Fusion Source is subtracted out from the "Full Scale" Geometry (including the TIVAR Collimator)...............................................................................68

Figure 43. Energy Spectra for both the Top and Bottom nTOF detectors at locations "C" and "D" in Figure 1 from shot z1549..................................................................................................................................................70
Figure 44. Neutrons Scattering after the Primary Pulse, coming in later in time, scattering through the sides of the pig, and scattering up from the floor.............72

Figure 45. The Elevator made into a "kill zone," eliminating the second "hump"..........73

Figure 46. Both the Elevator and sides of the pig made into "kill zones," eliminating both "humps" ........................................................................................................................................74

Figure 47. Idaho Accelerator Center (IAC) Layout.................................................................156

Figure 48. Experimental Time Response found at Idaho Accelerator Center using 50 ps bursts of x-rays...............................................................................................................................................157

Figure 49. The model of the first collimator used on the Z-machine.................................159

Figure 50. The new collimator design after the Z-machine was refurbished ..................160

Figure 51. The model with the old collimator for the bottom nTOF ("D" in Figure 1)....161

Figure 52. The model with the new collimator for the bottom nTOF ("D" in Figure 1)....162

Figure 53. The model with the old collimator for the top nTOF ("C" in Figure 1).........163

Figure 54. The model with the new collimator for the top nTOF ("C" in Figure 1).......164
LIST OF TABLES

Table I. Excerpt from MCNP-PoliMi Collision Data Output Table..........................9

Table II. Temporal Broadening due to Scintillator Thickness and Time Response
          for a 4 keV DD Fusion Source placed at 809 cm ................................................. 29

Table III. Broadening due to Scattering at Detector Location “D” with no Collimator.....57

Table IV. Integrals of $dN/dt$ (Figure 37) and $dN/dE$ (Figure 38).............................62

Table V. Broadening due to Scattering at Detector Location “C” with no Collimator......64

Table VI. Broadening due to Scattering at Detector Location “D” with a Collimator......67

Table VII. Broadening due to Scattering at Detector Location “C” with a Collimator......69

Table VIII. Broadening Due to Scattering for each Detector Location..........................69
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:

\[
D + D \rightarrow He^3(0.82 \text{ MeV}) + n(2.45 \text{ MeV})
\] (1)

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
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
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 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).**
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. 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-

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.
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.](image)
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 “Politecnico di Milano”) 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.*

<table>
<thead>
<tr>
<th>Projectile Type</th>
<th>Interaction Type</th>
<th>Target Nucleus</th>
<th>Energy Deposited in Collision (MeV)</th>
<th>Time (Shakes)</th>
<th>Number Of Scatterings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.52526</td>
<td>43.55</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.18983</td>
<td>84.74</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.01374</td>
<td>84.76</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>6000</td>
<td>0.01628</td>
<td>75.01</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>6000</td>
<td>0.00892</td>
<td>75.13</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.02221</td>
<td>75.27</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.01146</td>
<td>75.31</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>6000</td>
<td>0.00028</td>
<td>75.43</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.00036</td>
<td>75.49</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>1001</td>
<td>0.00080</td>
<td>78.30</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>6000</td>
<td>0.00012</td>
<td>78.74</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>-99</td>
<td>6000</td>
<td>0.01170</td>
<td>74.81</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>6</td>
<td>1.94631</td>
<td>62.74</td>
<td>1</td>
</tr>
</tbody>
</table>

91 = Neutron; 2 = photon; -99 = elastic scattering; 1 = Compton scattering; -1 = inelastic scattering; 1001 and 1 = Hydrogen; 6000 and 6 = Carbon; 1 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):

\[ L = 0.0364 \times E_n^2 + 0.125 \times E_n \]  

(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:

\[ L = 0.02 \times E_n^c \]  

(3)

where \( E_n^c \) 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:
$L = E_y$  \hspace{1cm} (4)

where $E_y$ 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](image-url)

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

Figure 10. An analog MCNP-PoliMi model (i.e., without any Variance Reduction Techniques applied). This was run with the maximum amount of particles ($2.0 \times 10^9$), and it took 43 hours of computer time.
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 loose 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:

\[ FOM = \frac{1}{R^2T} \]  

(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
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 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.
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.
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:

\[
(r \otimes s)_j \equiv \sum_{k=-M/2+1}^{M/2} s_{j-k} r_k
\]  

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:

\[
Temp = 16578.1944 \times \frac{(FWHM)^2}{D^2}
\]  

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:

\[
FWHM = \sqrt{(Temp \ FWHM)^2 + (Time \ Response \ FWHM)^2}
\]  

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.†

<table>
<thead>
<tr>
<th>Thickness of Scintillator</th>
<th>Broadening due to Thickness (ns)</th>
<th>Broadening due to Time Response (ns) Ave: &lt; 2.437 &gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3175 cm (1/8&quot;)</td>
<td>---</td>
<td>2.394</td>
</tr>
<tr>
<td>1.27 cm (1/2&quot;)</td>
<td>0.03</td>
<td>2.425</td>
</tr>
<tr>
<td>2.54 cm (1&quot;)</td>
<td>0.03</td>
<td>2.43</td>
</tr>
<tr>
<td>5.08 cm (2&quot;)</td>
<td>0.08</td>
<td>2.518</td>
</tr>
<tr>
<td>7.62 cm (3&quot;)</td>
<td>0.33</td>
<td>2.441</td>
</tr>
<tr>
<td>10.16 cm (4&quot;)</td>
<td>0.53</td>
<td>2.418</td>
</tr>
<tr>
<td>15.24 cm (6&quot;)</td>
<td>0.83</td>
<td>2.425</td>
</tr>
<tr>
<td>20.32 cm (8&quot;)</td>
<td>1.03</td>
<td>2.441</td>
</tr>
</tbody>
</table>

†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.
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.

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.
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.

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.

![Figure 18](image)

**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.
“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.

![Image of collimator](image)

**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.

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.

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.
(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.

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

![Graph showing data and zero-padding](image)

**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.

![Graph](image-url)

**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:

\[ KE = \frac{1}{2} m v^2 \]  \hspace{1cm} (9)

Substituting 2.45 MeV for \( KE \), letting \( m = m_0 \), and multiplying by \( c^2/c^2 \) gives:

\[ 2.45 \text{ MeV} = \frac{1}{2} \frac{v^2}{c^2} m_0 c^2 \]  \hspace{1cm} (10)

Solving for \( v/c \):

\[ \frac{v}{c} = \sqrt{\frac{(2)(2.45 \text{ MeV})}{m_0 c^2}} \]  \hspace{1cm} (11)

Letting \( c = 2.9979 \times 10^{10} \text{ cm/sec} \), and \( m_0 c^2 = 939.5653 \text{ MeV} \) for a neutron and solving for \( v \):

\[ v = \sqrt{(2)(2.45 \text{ MeV})} \left( \frac{2.9979 \times 10^{10} \text{ cm}}{\text{sec}} \right) \]  \hspace{1cm} (12)

\( v \) becomes:

\[ v = 2.166 \times 10^9 \text{ cm/sec} \left( \frac{1 \text{ sec}}{10^9 \text{ ns}} \right) \]  \hspace{1cm} (13)

Thus, the velocity of a 2.45 MeV neutron is:

\[ v = 2.166 \text{ cm/ns} \]  \hspace{1cm} (14)

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

\[ \text{Transit Time} = \frac{2.54 \text{ cm}}{2.166 \text{ cm/ns}} \]  \hspace{1cm} (51)
or:

\[
\text{Transit Time} = 1.17 \text{ ns} \tag{16}
\]

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 ns / 2 = 0.6 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:

\[
FWMH = \sqrt{(7.5 \text{ ns})^2 + (1.2 \text{ ns})^2}
\]  

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

\[
FWMH = 7.60 \text{ ns}
\]

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
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
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
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

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.
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.
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.

<table>
<thead>
<tr>
<th>Waveform</th>
<th>FWHM (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Full Scale” Geometry (Bottom nTOF)</td>
<td>16.375</td>
</tr>
<tr>
<td>“Ideal Case”</td>
<td>12.518</td>
</tr>
<tr>
<td>Broadening Due to Scattering:</td>
<td>16.375 - 12.518 = 3.857 ns</td>
</tr>
</tbody>
</table>

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 \textit{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:

\[
\frac{dN}{dt} = \frac{dN}{dE} \times \frac{dE}{dt}
\]  

(19)

Solving for \( dN/dE \):

\[
\frac{dN}{dE} = \frac{dN}{dt} \div \frac{dE}{dt}
\]  

(20)

From equation (9) above:

\[
E = \frac{1}{2} m \nu^2
\]  

(21)

Putting \( \nu \) in terms of \( t \):

\[
E = \frac{1}{2} m_0 \frac{c^2}{c^2} \left( \frac{1}{t} \right)^2
\]  

(22)

let \( m = m_0 c^2 = 939.5054 \text{ MeV} \), and taking the derivative of (22) with respect to \( t \):
\[ \frac{dE}{dt} = -\frac{m}{c^2} \frac{l^2}{t^3} \]  \hspace{1cm} (23)

Taking the absolute value of \( dE/\text{dt} \):

\[ \left| \frac{dE}{dt} \right| = +\frac{m}{c^2} \frac{l^2}{t^3} \]  \hspace{1cm} (24)

Solving for \( t \) in equation (22):

\[ t = \sqrt[3]{\frac{ml^2}{2c^2E}} \]  \hspace{1cm} (25)

And \( t^3 \) becomes:

\[ t^3 = \left[ \frac{ml^2}{2c^2E} \right]^{3/2} \]  \hspace{1cm} (26)

Substituting the value of \( dE/\text{dt} \) in (24) into (20) becomes:

\[ \frac{dN}{dE} = \frac{dN}{dt} * \frac{c^2 t^3}{ml^2} \]  \hspace{1cm} (27)

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

\[ \frac{dN}{dE} = \frac{dN}{dt} * \frac{c^2}{ml^2} \left( \frac{ml^2}{2c^2E} \right)^{3/2} \]  \hspace{1cm} (28)

Simplifying:

\[ \frac{dN}{dE} = \frac{m^{1/2} l}{2c \sqrt{2E}^{3/2}} * \frac{dN}{dt} \]  \hspace{1cm} (29)
Defining constants:

\[ K(l)_E = \frac{m^{1/2} l}{2c\sqrt{2}}, \text{and } K(l)_t = \frac{c^2}{ml^2} \]  

such that:

\[ \frac{dN}{dE} = K(l)_E \times \frac{dN}{dt} \times E^{-3/2} \]  

(30)

and:

\[ \frac{dN}{dE} = K(l)_t \times \frac{dN}{dt} \times t^3 \]  

(31)

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 \#/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.
According to the equation:

\[ \int_{E_{\text{min}}}^{E_{\text{max}}} \frac{dN}{dE} \, dE = \int_{t_{\text{min}}}^{t_{\text{max}}} \frac{dN}{dt} \, dt \]  

(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.
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.
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.

<table>
<thead>
<tr>
<th>Waveform</th>
<th>FWHM (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Full Scale” Geometry (Bottom nTOF)</td>
<td>15.11</td>
</tr>
<tr>
<td>“Ideal Case”</td>
<td>11.220</td>
</tr>
<tr>
<td>Broadening Due to Scattering:</td>
<td>15.11 – 11.220 = 3.89 ns</td>
</tr>
</tbody>
</table>

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”
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.

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.
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

![Graph showing reduction in scattering]

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.

The 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.

<table>
<thead>
<tr>
<th>Waveform</th>
<th>FWHM (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Full Scale” Geometry (Bottom nTOF)</td>
<td>11.84</td>
</tr>
<tr>
<td>“Ideal Case”</td>
<td>8.991</td>
</tr>
<tr>
<td>Broadening due to Scattering:</td>
<td>11.84 – 8.991 = 2.849 ns</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Waveform</th>
<th>FWHM (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Full Scale” Geometry (Top nTOF)</td>
<td>11.20</td>
</tr>
<tr>
<td>“Ideal Case”</td>
<td>8.024</td>
</tr>
<tr>
<td>Broadening due to Scattering:</td>
<td>11.2 – 8.024 = 3.176 ns</td>
</tr>
</tbody>
</table>

Table VIII.

Broadening Due to Scattering for each Detector Location

<table>
<thead>
<tr>
<th>Detector Location</th>
<th>Without Collimator (ns)</th>
<th>With Collimator (ns)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom nTOF, (“D”)</td>
<td>3.857</td>
<td>2.849</td>
<td>26.1</td>
</tr>
<tr>
<td>Top nTOF, (“C”)</td>
<td>3.89</td>
<td>3.176</td>
<td>18.4</td>
</tr>
</tbody>
</table>
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.

![Graph](image)

**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.

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.

![Graph showing normalized amplitude over time](image)

**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:

\[ D + T \rightarrow \alpha (3.5 \text{ MeV}) + n(14.1 \text{ MeV}) \] (34)

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 \( \rho R \) of the fuel (\( g/cm^2 \)). Here \( \rho \) 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 \( \rho R \) is \( \sim 3g/cm^2 \) [34]. For low values of \( \rho R \), disassembly of the pellet becomes an issue, and for high values of \( \rho R \), 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 \( \rho R \) 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 \( \rho R \) attained in a pellet implosion is an extremely critical measure of pellet performance [35].
Unfortunately, $\rho R$ is a difficult quantity to measure. One potential way to measure the $\rho R$ 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 $\rho R$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 $\rho R$, so if the $dsf$ can be measured, the fuel $\rho R$ 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 $\rho R$ measurements of D-D fusion experiments. In the case of D-D fusion there are two reactions of roughly equal probability:

\[
D + D \rightarrow He^3(0.82 \text{ MeV}) + n (2.45 \text{ MeV}) \tag{35}
\]

\[
D + D \rightarrow T(1.01 \text{ MeV}) + p(3.04 \text{ MeV}) \tag{36}
\]

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 $\rho R$ of the fuel, so measuring the ratio of D-D to D-T neutrons will give a measure of the fuel.
$\rho R$. 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 $\rho R$.

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.
APPENDIX A
MCNP-PoliMi INPUT DECK

INPUT DECK

BOTTOM nTOF W/ TIVAR COLLIMATOR

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

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
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 $ **************

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

52 0 46 -74 -23 $ Void Inside Collimator Cone
53 2 -19.2 36 -37 25 -24 $ **************
54 3 -0.93 36 -37 24 -12
<p>| 55 | 3 | -0.93 | 36 | -37 | 12 | -140 |
| 56 | 3 | -0.93 | 36 | -37 | 140 | -758 |
| 57 | 2 | -19.2 | 37 | -38 | 25 | -24 |
| 58 | 3 | -0.93 | 37 | -38 | 24 | -12 |
| 59 | 3 | -0.93 | 37 | -38 | 12 | -140 |
| 60 | 3 | -0.93 | 37 | -38 | 140 | -758 |
| 61 | 2 | -19.2 | 38 | -39 | 25 | -24 |
| 62 | 3 | -0.93 | 38 | -39 | 24 | -12 |
| 63 | 3 | -0.93 | 38 | -39 | 12 | -140 |
| 64 | 3 | -0.93 | 38 | -39 | 140 | -758 |
| 65 | 2 | -19.2 | 39 | -40 | 25 | -24 |
| 66 | 3 | -0.93 | 39 | -40 | 24 | -12 |
| 67 | 3 | -0.93 | 39 | -40 | 12 | -140 |
| 68 | 3 | -0.93 | 39 | -40 | 140 | -758 |
| 69 | 2 | -19.2 | 40 | -41 | 25 | -24 |
| 70 | 3 | -0.93 | 40 | -41 | 24 | -12 |
| 71 | 3 | -0.93 | 40 | -41 | 12 | -140 |
| 72 | 3 | -0.93 | 40 | -41 | 140 | -758 |
| 73 | 2 | -19.2 | 41 | -42 | 25 | -24 |
| 74 | 3 | -0.93 | 41 | -42 | 24 | -12 |
| 75 | 3 | -0.93 | 41 | -42 | 12 | -140 |
| 76 | 3 | -0.93 | 41 | -42 | 140 | -758 |
| 77 | 2 | -19.2 | 42 | -43 | 25 | -24 |
| 78 | 3 | -0.93 | 42 | -43 | 24 | -12 |
| 79 | 3 | -0.93 | 42 | -43 | 12 | -140 |
| 80 | 3 | -0.93 | 42 | -43 | 140 | -758 |
| 81 | 2 | -19.2 | 43 | -44 | 25 | -24 |
| 82 | 3 | -0.93 | 43 | -44 | 24 | -12 |
| 83 | 3 | -0.93 | 43 | -44 | 12 | -140 |
| 84 | 3 | -0.93 | 43 | -44 | 140 | -758 |
| 85 | 2 | -19.2 | 44 | -45 | 25 | -24 |
| 86 | 3 | -0.93 | 44 | -45 | 24 | -12 |
| 87 | 3 | -0.93 | 44 | -45 | 12 | -140 |
| 88 | 3 | -0.93 | 44 | -45 | 140 | -758 |
| 89 | 2 | -19.2 | 45 | -46 | 25 | -24 |
| 90 | 3 | -0.93 | 45 | -46 | 24 | -12 |
| 91 | 3 | -0.93 | 45 | -46 | 12 | -140 |
| 92 | 3 | -0.93 | 45 | -46 | 140 | -758 |
| 93 | 0 | 46 | -54 | -23 |
| 94 | 0 | 47 | -48 | 25 | -24 |
| 95 | 0 | 48 | -49 | 25 | -24 |
| 96 | 0 | 49 | -50 | 25 | -24 |
| 97 | 0 | 50 | -51 | 25 | -24 |
| 98 | 0 | 51 | -52 | 25 | -24 |
| 99 | 0 | 52 | -53 | 25 | -24 |
| 100 | 0 | 53 | -54 | 25 | -24 |
| 101 | 0 | 13 | -46 | -25 |
| 102 | 0 | 55 | -56 | 25 | -24 |
| 103 | 0 | 56 | -57 | 25 | -24 |
| 104 | 0 | 57 | -58 | 25 | -24 |</p>
<table>
<thead>
<tr>
<th>c 105</th>
<th>0 58 -59 25 -24</th>
</tr>
</thead>
<tbody>
<tr>
<td>c 106</td>
<td>0 59 -60 25 -24</td>
</tr>
<tr>
<td>c 107</td>
<td>0 60 -61 25 -24</td>
</tr>
<tr>
<td>c 108</td>
<td>0 61 -62 25 -24</td>
</tr>
<tr>
<td>c 109</td>
<td>0 62 -63 25 -24</td>
</tr>
<tr>
<td>c 110</td>
<td>0 63 -64 25 -24</td>
</tr>
<tr>
<td>c 111</td>
<td>0 64 -65 25 -24</td>
</tr>
<tr>
<td>c 112</td>
<td>0 65 -66 25 -24 $ ****************************</td>
</tr>
<tr>
<td>c 113</td>
<td>0 46 -47 24 -142 $ ****************************</td>
</tr>
<tr>
<td>c 114</td>
<td>0 46 -47 142 -140</td>
</tr>
<tr>
<td>c 115</td>
<td>0 46 -47 140 -141</td>
</tr>
<tr>
<td>c 116</td>
<td>0 47 -48 24 -142</td>
</tr>
<tr>
<td>c 117</td>
<td>0 47 -48 142 -140</td>
</tr>
<tr>
<td>c 118</td>
<td>0 47 -48 140 -141</td>
</tr>
<tr>
<td>c 119</td>
<td>0 48 -49 24 -142</td>
</tr>
<tr>
<td>c 120</td>
<td>0 48 -49 142 -140</td>
</tr>
<tr>
<td>c 121</td>
<td>0 48 -49 140 -141</td>
</tr>
<tr>
<td>c 122</td>
<td>0 49 -50 24 -142</td>
</tr>
<tr>
<td>c 123</td>
<td>0 49 -50 142 -140</td>
</tr>
<tr>
<td>c 124</td>
<td>0 49 -50 140 -141 $ Cells where more TIVAR</td>
</tr>
<tr>
<td>c 125</td>
<td>0 50 -51 24 -142 $ can be added to the</td>
</tr>
<tr>
<td>c 126</td>
<td>0 50 -51 142 -140 $ 25.4 cm (10 in) length</td>
</tr>
<tr>
<td>c 127</td>
<td>0 50 -51 140 -141</td>
</tr>
<tr>
<td>c 128</td>
<td>0 51 -52 24 -142</td>
</tr>
<tr>
<td>c 129</td>
<td>0 51 -52 142 -140</td>
</tr>
<tr>
<td>c 130</td>
<td>0 51 -52 140 -141</td>
</tr>
<tr>
<td>c 131</td>
<td>0 52 -53 24 -142</td>
</tr>
<tr>
<td>c 132</td>
<td>0 52 -53 142 -140</td>
</tr>
<tr>
<td>c 133</td>
<td>0 52 -53 140 -141</td>
</tr>
<tr>
<td>c 134</td>
<td>0 53 -54 24 -142</td>
</tr>
<tr>
<td>c 135</td>
<td>0 53 -54 142 -140</td>
</tr>
<tr>
<td>c 136</td>
<td>0 53 -54 140 -141 $ ****************************</td>
</tr>
<tr>
<td>c 137</td>
<td>0 66 -74 -23 $ ****************************</td>
</tr>
<tr>
<td>c 138</td>
<td>0 139 -67 25 -24</td>
</tr>
<tr>
<td>c 139</td>
<td>0 139 -67 24 -142</td>
</tr>
<tr>
<td>c 140</td>
<td>0 67 -68 -25</td>
</tr>
<tr>
<td>c 141</td>
<td>0 67 -68 25 -24</td>
</tr>
<tr>
<td>c 142</td>
<td>0 67 -68 24 -142</td>
</tr>
<tr>
<td>c 143</td>
<td>0 68 -69 -25</td>
</tr>
<tr>
<td>c 144</td>
<td>0 68 -69 25 -24</td>
</tr>
<tr>
<td>c 145</td>
<td>0 68 -69 24 -142</td>
</tr>
<tr>
<td>c 146</td>
<td>0 69 -70 -25</td>
</tr>
<tr>
<td>c 147</td>
<td>0 69 -70 25 -142</td>
</tr>
<tr>
<td>c 148</td>
<td>0 69 -70 24 -142 $ Cells where more TIVAR</td>
</tr>
<tr>
<td>c 149</td>
<td>0 70 -71 -25 $ can be added to the</td>
</tr>
<tr>
<td>c 150</td>
<td>0 70 -71 25 -142 $ 50.8 cm (20 in) length</td>
</tr>
<tr>
<td>c 151</td>
<td>0 70 -71 24 -142</td>
</tr>
<tr>
<td>c 152</td>
<td>0 71 -72 -25</td>
</tr>
<tr>
<td>c 153</td>
<td>0 71 -72 25 -142</td>
</tr>
<tr>
<td>c 154</td>
<td>0 71 -72 24 -142</td>
</tr>
<tr>
<td>c 155</td>
<td>0 72 -73 -25</td>
</tr>
<tr>
<td>c 156</td>
<td>0 72 -73 25 -142</td>
</tr>
<tr>
<td>c 157</td>
<td>0 72 -73 24 -142</td>
</tr>
<tr>
<td>c 158</td>
<td>0 73 -74 -25</td>
</tr>
<tr>
<td>c 159</td>
<td>0 73 -74 25 -142</td>
</tr>
<tr>
<td>c 160</td>
<td>0 73 -74 24 -142 $ ****************************</td>
</tr>
<tr>
<td>c 161</td>
<td>0 54 -66 142 -23</td>
</tr>
<tr>
<td>c 162</td>
<td>1 -7.9 13 -27 23 -22 $ ****************************</td>
</tr>
<tr>
<td>c 163</td>
<td>1 -7.9 27 -28 23 -22</td>
</tr>
<tr>
<td>c 164</td>
<td>1 -7.9 28 -29 23 -22</td>
</tr>
<tr>
<td>c 165</td>
<td>1 -7.9 29 -30 23 -22</td>
</tr>
<tr>
<td>c 166</td>
<td>1 -7.9 30 -31 23 -22</td>
</tr>
<tr>
<td>c 167</td>
<td>1 -7.9 31 -32 23 -22</td>
</tr>
<tr>
<td>c 168</td>
<td>1 -7.9 32 -33 23 -22</td>
</tr>
<tr>
<td>c 169</td>
<td>1 -7.9 33 -34 23 -22</td>
</tr>
<tr>
<td>c 170</td>
<td>1 -7.9 34 -35 23 -22</td>
</tr>
<tr>
<td>c 171</td>
<td>1 -7.9 35 -36 23 -22</td>
</tr>
<tr>
<td>c 172</td>
<td>1 -7.9 36 -37 23 -22</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>173</td>
<td></td>
</tr>
<tr>
<td>176</td>
<td></td>
</tr>
<tr>
<td>179</td>
<td></td>
</tr>
<tr>
<td>182</td>
<td></td>
</tr>
<tr>
<td>185</td>
<td></td>
</tr>
<tr>
<td>188</td>
<td></td>
</tr>
<tr>
<td>191</td>
<td></td>
</tr>
<tr>
<td>194</td>
<td></td>
</tr>
<tr>
<td>197</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>203</td>
<td></td>
</tr>
<tr>
<td>206</td>
<td></td>
</tr>
<tr>
<td>209</td>
<td></td>
</tr>
<tr>
<td>212</td>
<td></td>
</tr>
<tr>
<td>215</td>
<td></td>
</tr>
<tr>
<td>218</td>
<td></td>
</tr>
<tr>
<td>221</td>
<td></td>
</tr>
<tr>
<td>224</td>
<td></td>
</tr>
<tr>
<td>227</td>
<td></td>
</tr>
<tr>
<td>230</td>
<td></td>
</tr>
<tr>
<td>233</td>
<td></td>
</tr>
<tr>
<td>236</td>
<td></td>
</tr>
<tr>
<td>239</td>
<td></td>
</tr>
<tr>
<td>242</td>
<td></td>
</tr>
</tbody>
</table>

$ MITL $ Cone
<table>
<thead>
<tr>
<th>Cell</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>245</td>
<td>1</td>
<td>7.9</td>
<td>109</td>
<td>110</td>
</tr>
<tr>
<td>246</td>
<td>1</td>
<td>7.9</td>
<td>110</td>
<td>111</td>
</tr>
<tr>
<td>247</td>
<td>1</td>
<td>7.9</td>
<td>111</td>
<td>112</td>
</tr>
<tr>
<td>248</td>
<td>1</td>
<td>7.9</td>
<td>112</td>
<td>113</td>
</tr>
<tr>
<td>249</td>
<td>1</td>
<td>7.9</td>
<td>113</td>
<td>114</td>
</tr>
<tr>
<td>250</td>
<td>1</td>
<td>7.9</td>
<td>114</td>
<td>115</td>
</tr>
<tr>
<td>251</td>
<td>1</td>
<td>7.9</td>
<td>115</td>
<td>116</td>
</tr>
<tr>
<td>252</td>
<td>1</td>
<td>7.9</td>
<td>116</td>
<td>117</td>
</tr>
<tr>
<td>253</td>
<td>1</td>
<td>7.9</td>
<td>117</td>
<td>118</td>
</tr>
<tr>
<td>254</td>
<td>1</td>
<td>7.9</td>
<td>119</td>
<td>120</td>
</tr>
<tr>
<td>255</td>
<td>1</td>
<td>7.9</td>
<td>120</td>
<td>121</td>
</tr>
<tr>
<td>256</td>
<td>1</td>
<td>7.9</td>
<td>121</td>
<td>122</td>
</tr>
<tr>
<td>257</td>
<td>1</td>
<td>7.9</td>
<td>122</td>
<td>123</td>
</tr>
<tr>
<td>258</td>
<td>1</td>
<td>7.9</td>
<td>123</td>
<td>124</td>
</tr>
<tr>
<td>259</td>
<td>1</td>
<td>7.9</td>
<td>124</td>
<td>125</td>
</tr>
<tr>
<td>260</td>
<td>1</td>
<td>7.9</td>
<td>125</td>
<td>126</td>
</tr>
<tr>
<td>261</td>
<td>1</td>
<td>7.9</td>
<td>126</td>
<td>127</td>
</tr>
<tr>
<td>262</td>
<td>1</td>
<td>7.9</td>
<td>127</td>
<td>128</td>
</tr>
<tr>
<td>263</td>
<td>1</td>
<td>7.9</td>
<td>128</td>
<td>129</td>
</tr>
<tr>
<td>264</td>
<td>1</td>
<td>7.9</td>
<td>129</td>
<td>130</td>
</tr>
<tr>
<td>265</td>
<td>1</td>
<td>7.9</td>
<td>130</td>
<td>131</td>
</tr>
<tr>
<td>266</td>
<td>1</td>
<td>7.9</td>
<td>131</td>
<td>132</td>
</tr>
<tr>
<td>267</td>
<td>1</td>
<td>7.9</td>
<td>132</td>
<td>133</td>
</tr>
<tr>
<td>268</td>
<td>1</td>
<td>7.9</td>
<td>133</td>
<td>134</td>
</tr>
<tr>
<td>269</td>
<td>1</td>
<td>7.9</td>
<td>134</td>
<td>135</td>
</tr>
<tr>
<td>270</td>
<td>1</td>
<td>7.9</td>
<td>135</td>
<td>136</td>
</tr>
<tr>
<td>271</td>
<td>1</td>
<td>7.9</td>
<td>136</td>
<td>137</td>
</tr>
<tr>
<td>272</td>
<td>0</td>
<td>9</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>273</td>
<td>0</td>
<td>106</td>
<td>-106</td>
<td>-25</td>
</tr>
<tr>
<td>274</td>
<td>0</td>
<td>16</td>
<td>-17</td>
<td>-20</td>
</tr>
<tr>
<td>275</td>
<td>6</td>
<td>-1.032</td>
<td>18</td>
<td>-460</td>
</tr>
<tr>
<td>276</td>
<td>0</td>
<td>671</td>
<td>-672</td>
<td>137</td>
</tr>
<tr>
<td>277</td>
<td>0</td>
<td>672</td>
<td>-671</td>
<td>931</td>
</tr>
<tr>
<td>278</td>
<td>0</td>
<td>66</td>
<td>-139</td>
<td>25</td>
</tr>
<tr>
<td>279</td>
<td>0</td>
<td>66</td>
<td>-139</td>
<td>25</td>
</tr>
<tr>
<td>280</td>
<td>0</td>
<td>66</td>
<td>-139</td>
<td>25</td>
</tr>
<tr>
<td>281</td>
<td>0</td>
<td>1</td>
<td>-3</td>
<td>144</td>
</tr>
<tr>
<td>282</td>
<td>0</td>
<td>3</td>
<td>-5</td>
<td>144</td>
</tr>
<tr>
<td>283</td>
<td>0</td>
<td>7</td>
<td>-9</td>
<td>144</td>
</tr>
<tr>
<td>284</td>
<td>0</td>
<td>434</td>
<td>-430</td>
<td>680</td>
</tr>
<tr>
<td>285</td>
<td>0</td>
<td>17</td>
<td>-149</td>
<td>-20</td>
</tr>
<tr>
<td>286</td>
<td>0</td>
<td>434</td>
<td>-430</td>
<td>680</td>
</tr>
<tr>
<td>287</td>
<td>0</td>
<td>13</td>
<td>-32</td>
<td>141</td>
</tr>
<tr>
<td>288</td>
<td>0</td>
<td>27</td>
<td>-28</td>
<td>141</td>
</tr>
<tr>
<td>289</td>
<td>0</td>
<td>28</td>
<td>-29</td>
<td>141</td>
</tr>
<tr>
<td>290</td>
<td>0</td>
<td>29</td>
<td>-30</td>
<td>141</td>
</tr>
<tr>
<td>291</td>
<td>0</td>
<td>30</td>
<td>-31</td>
<td>141</td>
</tr>
<tr>
<td>292</td>
<td>0</td>
<td>31</td>
<td>-32</td>
<td>141</td>
</tr>
<tr>
<td>293</td>
<td>0</td>
<td>32</td>
<td>-33</td>
<td>141</td>
</tr>
<tr>
<td>294</td>
<td>0</td>
<td>33</td>
<td>-34</td>
<td>141</td>
</tr>
<tr>
<td>295</td>
<td>0</td>
<td>34</td>
<td>-35</td>
<td>141</td>
</tr>
<tr>
<td>296</td>
<td>0</td>
<td>35</td>
<td>-36</td>
<td>141</td>
</tr>
<tr>
<td>297</td>
<td>0</td>
<td>36</td>
<td>-37</td>
<td>141</td>
</tr>
<tr>
<td>298</td>
<td>0</td>
<td>37</td>
<td>-38</td>
<td>141</td>
</tr>
<tr>
<td>299</td>
<td>0</td>
<td>38</td>
<td>-39</td>
<td>141</td>
</tr>
<tr>
<td>300</td>
<td>0</td>
<td>39</td>
<td>-40</td>
<td>141</td>
</tr>
<tr>
<td>301</td>
<td>0</td>
<td>40</td>
<td>-41</td>
<td>141</td>
</tr>
<tr>
<td>302</td>
<td>0</td>
<td>41</td>
<td>-42</td>
<td>141</td>
</tr>
<tr>
<td>303</td>
<td>0</td>
<td>42</td>
<td>-43</td>
<td>141</td>
</tr>
<tr>
<td>304</td>
<td>0</td>
<td>43</td>
<td>-44</td>
<td>141</td>
</tr>
<tr>
<td>305</td>
<td>0</td>
<td>44</td>
<td>-45</td>
<td>141</td>
</tr>
</tbody>
</table>
More Tivar to "Shadow" the pig to twice its radius (from 54.61 cm to 109.22 cm)

****************************
<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>374</td>
<td>0</td>
<td>83</td>
<td>-84</td>
<td>24</td>
<td>-142   $ Cells where more TIVAR $ Can be added to Collimator</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>375</td>
<td>0</td>
<td>83</td>
<td>-84</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>376</td>
<td>0</td>
<td>84</td>
<td>-85</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>377</td>
<td>0</td>
<td>84</td>
<td>-85</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>378</td>
<td>0</td>
<td>84</td>
<td>-85</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>379</td>
<td>0</td>
<td>84</td>
<td>-85</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>0</td>
<td>85</td>
<td>-86</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>381</td>
<td>0</td>
<td>85</td>
<td>-86</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>382</td>
<td>0</td>
<td>85</td>
<td>-86</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>383</td>
<td>0</td>
<td>85</td>
<td>-86</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>384</td>
<td>0</td>
<td>86</td>
<td>-87</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>385</td>
<td>0</td>
<td>86</td>
<td>-87</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>386</td>
<td>0</td>
<td>86</td>
<td>-87</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>387</td>
<td>0</td>
<td>86</td>
<td>-87</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>388</td>
<td>0</td>
<td>87</td>
<td>-88</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>389</td>
<td>0</td>
<td>87</td>
<td>-88</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>390</td>
<td>0</td>
<td>87</td>
<td>-88</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>391</td>
<td>0</td>
<td>87</td>
<td>-88</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>392</td>
<td>0</td>
<td>88</td>
<td>-89</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>393</td>
<td>0</td>
<td>88</td>
<td>-89</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>394</td>
<td>0</td>
<td>88</td>
<td>-89</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>395</td>
<td>0</td>
<td>88</td>
<td>-89</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>396</td>
<td>0</td>
<td>89</td>
<td>-90</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>397</td>
<td>0</td>
<td>89</td>
<td>-90</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>398</td>
<td>0</td>
<td>89</td>
<td>-90</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>399</td>
<td>0</td>
<td>89</td>
<td>-90</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>0</td>
<td>90</td>
<td>-91</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>401</td>
<td>0</td>
<td>90</td>
<td>-91</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>402</td>
<td>0</td>
<td>90</td>
<td>-91</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>403</td>
<td>0</td>
<td>90</td>
<td>-91</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>404</td>
<td>0</td>
<td>91</td>
<td>-92</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>405</td>
<td>0</td>
<td>91</td>
<td>-92</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>406</td>
<td>0</td>
<td>91</td>
<td>-92</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>407</td>
<td>0</td>
<td>91</td>
<td>-92</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>408</td>
<td>0</td>
<td>92</td>
<td>-93</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>409</td>
<td>0</td>
<td>92</td>
<td>-93</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>410</td>
<td>0</td>
<td>92</td>
<td>-93</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>411</td>
<td>0</td>
<td>92</td>
<td>-93</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>412</td>
<td>0</td>
<td>93</td>
<td>-94</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>413</td>
<td>0</td>
<td>93</td>
<td>-94</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>414</td>
<td>0</td>
<td>93</td>
<td>-94</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>415</td>
<td>0</td>
<td>93</td>
<td>-94</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>416</td>
<td>0</td>
<td>94</td>
<td>-95</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>417</td>
<td>0</td>
<td>94</td>
<td>-95</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>418</td>
<td>0</td>
<td>94</td>
<td>-95</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>419</td>
<td>0</td>
<td>94</td>
<td>-95</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>420</td>
<td>0</td>
<td>95</td>
<td>-96</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>421</td>
<td>0</td>
<td>95</td>
<td>-96</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>422</td>
<td>0</td>
<td>95</td>
<td>-96</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>423</td>
<td>0</td>
<td>95</td>
<td>-96</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>424</td>
<td>0</td>
<td>96</td>
<td>-97</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>425</td>
<td>0</td>
<td>96</td>
<td>-97</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>426</td>
<td>0</td>
<td>96</td>
<td>-97</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>427</td>
<td>0</td>
<td>96</td>
<td>-97</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>428</td>
<td>0</td>
<td>97</td>
<td>-98</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>429</td>
<td>0</td>
<td>97</td>
<td>-98</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>430</td>
<td>0</td>
<td>97</td>
<td>-98</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>431</td>
<td>0</td>
<td>97</td>
<td>-98</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>432</td>
<td>0</td>
<td>98</td>
<td>-99</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>433</td>
<td>0</td>
<td>98</td>
<td>-99</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>434</td>
<td>0</td>
<td>98</td>
<td>-99</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>435</td>
<td>0</td>
<td>98</td>
<td>-99</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>436</td>
<td>0</td>
<td>99</td>
<td>-100</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>437</td>
<td>0</td>
<td>99</td>
<td>-100</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>438</td>
<td>0</td>
<td>99</td>
<td>-100</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>439</td>
<td>0</td>
<td>99</td>
<td>-100</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>440</td>
<td>0</td>
<td>100</td>
<td>-101</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>441</td>
<td>0</td>
<td>100</td>
<td>-101</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>442</td>
<td>0</td>
<td>100</td>
<td>-101</td>
<td>24</td>
<td>-142</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>443</td>
<td>0</td>
<td>100</td>
<td>-101</td>
<td>142</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>444</td>
<td>0</td>
<td>101</td>
<td>-102</td>
<td>-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>445</td>
<td>0</td>
<td>101</td>
<td>-102</td>
<td>25</td>
<td>-24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
$ 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
1 -7.9 39 -40 143 -144
1 -7.9 40 -41 143 -144
1 -7.9 41 -42 143 -144
1 -7.9 42 -43 143 -144
1 -7.9 43 -44 143 -144
1 -7.9 44 -45 143 -144
1 -7.9 45 -46 143 -144
1 -7.9 46 -47 143 -144
1 -7.9 47 -48 143 -144
1 -7.9 48 -49 143 -144
1 -7.9 49 -50 143 -144
1 -7.9 50 -51 143 -144
1 -7.9 51 -52 143 -144
1 -7.9 52 -53 143 -144
1 -7.9 53 -54 143 -144
1 -7.9 54 -55 143 -144
1 -7.9 55 -56 143 -144
1 -7.9 56 -57 143 -144
1 -7.9 57 -58 143 -144
1 -7.9 58 -59 143 -144
1 -7.9 59 -60 143 -144
1 -7.9 60 -61 143 -144
1 -7.9 61 -62 143 -144
1 -7.9 62 -63 143 -144
1 -7.9 63 -64 143 -144
1 -7.9 64 -65 143 -144
1 -7.9 65 -66 143 -144
1 -7.9 66 -67 143 -144
1 -7.9 67 -68 143 -144
1 -7.9 68 -69 143 -144
1 -7.9 69 -70 143 -144
1 -7.9 70 -71 143 -144
1 -7.9 71 -72 143 -144
1 -7.9 72 -73 143 -144
1 -7.9 73 -74 143 -144
1 -7.9 74 -75 143 -144
1 -7.9 75 -76 143 -144
1 -7.9 76 -77 143 -144
1 -7.9 77 -78 143 -144
1 -7.9 78 -79 143 -144
1 -7.9 79 -80 143 -144
1 -7.9 80 -81 143 -144
1 -7.9 81 -82 143 -144
1 -7.9 82 -83 143 -144
1 -7.9 83 -84 143 -144
1 -7.9 84 -85 143 -144
1 -7.9 85 -86 143 -144
1 -7.9 86 -87 143 -144
1 -7.9 87 -88 143 -144
1 -7.9 88 -89 143 -144
1 -7.9 89 -90 143 -144
1 -7.9 90 -91 143 -144
1 -7.9 91 -92 143 -144
1 -7.9 92 -93 143 -144
1 -7.9 93 -94 143 -144
1 -7.9 94 -95 143 -144
1 -7.9 95 -96 143 -144
1 -7.9 96 -97 143 -144
1 -7.9 97 -98 143 -144
1 -7.9 98 -99 143 -144
1 -7.9 99 -100 143 -144
1 -7.9 100 -101 143 -144
1 -7.9 101 -102 143 -144
1 -7.9 102 -103 143 -144
1 -7.9 103 -104 143 -144
1 -7.9 104 -105 143 -144
1 -7.9 105 -106 143 -144
1 -7.9 106 -107 143 -144
1 -7.9 107 -108 143 -144
1 -7.9 108 -109 143 -144
1 -7.9 109 -110 143 -144
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
585 1 -7.9  114 -115 143 -144
586 1 -7.9  115 -116 143 -144
587 1 -7.9  116 -117 143 -144
588 1 -7.9  117 -118 143 -144
589 1 -7.9  118 -119 143 -144
590 1 -7.9  119 -120 143 -144
591 1 -7.9  120 -121 143 -144
592 1 -7.9  121 -122 143 -144
593 1 -7.9  122 -123 143 -144
594 1 -7.9  123 -124 143 -144
595 1 -7.9  124 -125 143 -144
596 1 -7.9  125 -126 143 -144
597 1 -7.9  126 -127 143 -144
598 1 -7.9  127 -128 143 -144
  $ ********************
599 1 -7.9  17 -150 20 -21
600 1 -7.9  150 -151 20 -21
601 1 -7.9  151 -152 20 -21
602 1 -7.9  152 -153 20 -21
603 1 -7.9  153 -154 20 -21
604 1 -7.9  154 -155 20 -21
605 1 -7.9  155 -156 20 -21
606 1 -7.9  156 -157 20 -21
607 1 -7.9  157 -158 20 -21
608 1 -7.9  158 -159 20 -21
609 1 -7.9  159 -160 20 -21
610 1 -7.9  160 -161 20 -21
611 1 -7.9  161 -162 20 -21
612 1 -7.9  162 -163 20 -21
  $ Cylinder Extention on MITL #1
613 1 -7.9  163 -164 20 -21
614 1 -7.9  164 -165 20 -21
615 1 -7.9  165 -166 20 -21
616 1 -7.9  166 -167 20 -21
617 1 -7.9  167 -168 20 -21
618 1 -7.9  168 -169 20 -21
619 1 -7.9  169 -170 20 -21
620 1 -7.9  170 -171 20 -21
621 1 -7.9  171 -172 20 -21
622 1 -7.9  172 -173 20 -21
623 1 -7.9  173 -174 20 -21
624 1 -7.9  174 -175 20 -21
625 1 -7.9  175 -176 20 -21
626 1 -7.9  176 -177 20 -21
627 1 -7.9  177 -178 20 -21
628 1 -7.9  178 -179 20 -21
629 1 -7.9  179 -149 20 -21
  $ ********************
630 0  149 -148 146 -147
  $ Stack
631 0  434 -430 21 -147 680 -684
  $ Void at end to cover expansion of Stack
632 1 -7.9  1 -2 146 -147
  $ ********************
| 721 | 1 | -7.9 | 105 | -106 | 146 | -147 |
| 722 | 1 | -7.9 | 106 | -107 | 146 | -147 |
| 723 | 1 | -7.9 | 107 | -108 | 146 | -147 |
| 724 | 1 | -7.9 | 108 | -109 | 146 | -147 |
| 725 | 1 | -7.9 | 109 | -110 | 146 | -147 |
| 726 | 1 | -7.9 | 110 | -111 | 146 | -147 |
| 727 | 1 | -7.9 | 111 | -112 | 146 | -147 |
| 728 | 1 | -7.9 | 112 | -113 | 146 | -147 |
| 729 | 1 | -7.9 | 113 | -114 | 146 | -147 |
| 730 | 1 | -7.9 | 114 | -115 | 146 | -147 |
| 731 | 1 | -7.9 | 115 | -116 | 146 | -147 |
| 732 | 1 | -7.9 | 116 | -117 | 146 | -147 |
| 733 | 1 | -7.9 | 117 | -118 | 146 | -147 |
| 734 | 1 | -7.9 | 118 | -119 | 146 | -147 |
| 735 | 1 | -7.9 | 119 | -120 | 146 | -147 |
| 736 | 1 | -7.9 | 120 | -121 | 146 | -147 |
| 737 | 1 | -7.9 | 121 | -122 | 146 | -147 |
| 738 | 1 | -7.9 | 122 | -123 | 146 | -147 |
| 739 | 1 | -7.9 | 123 | -124 | 146 | -147 |
| 740 | 1 | -7.9 | 124 | -125 | 146 | -147 |
| 741 | 1 | -7.9 | 125 | -126 | 146 | -147 |
| 742 | 1 | -7.9 | 126 | -127 | 146 | -147 |
| 743 | 1 | -7.9 | 127 | -128 | 146 | -147 |
| 744 | 1 | -7.9 | 128 | -129 | 146 | -147 |
| 745 | 1 | -7.9 | 129 | -130 | 146 | -147 |
| 746 | 1 | -7.9 | 130 | -131 | 146 | -147 |
| 747 | 1 | -7.9 | 131 | -132 | 146 | -147 |
| 748 | 1 | -7.9 | 132 | -133 | 146 | -147 |
| 749 | 1 | -7.9 | 133 | -134 | 146 | -147 |
| 750 | 1 | -7.9 | 134 | -135 | 146 | -147 |
| 751 | 1 | -7.9 | 135 | -136 | 146 | -147 |
| 752 | 1 | -7.9 | 136 | -137 | 146 | -147 |
| 753 | 1 | -7.9 | 137 | -138 | 146 | -147 |
| 754 | 1 | -7.9 | 138 | -139 | 146 | -147 |
| 755 | 1 | -7.9 | 139 | -140 | 146 | -147 |
| 756 | 1 | -7.9 | 140 | -141 | 146 | -147 |
| 757 | 1 | -7.9 | 141 | -142 | 146 | -147 |
| 758 | 1 | -7.9 | 142 | -143 | 146 | -147 |
| 759 | 1 | -7.9 | 143 | -144 | 146 | -147 |
| 760 | 1 | -7.9 | 144 | -145 | 146 | -147 |
| 761 | 1 | -7.9 | 145 | -146 | 146 | -147 |
| 762 | 1 | -7.9 | 146 | -147 | 146 | -147 |
| 763 | 1 | -7.9 | 147 | -148 | 146 | -147 |
| 764 | 1 | -7.9 | 148 | -149 | 146 | -147 |
| 765 | 1 | -7.9 | 149 | -150 | 146 | -147 |
| 766 | 1 | -7.9 | 150 | -151 | 146 | -147 |
| 767 | 1 | -7.9 | 151 | -152 | 146 | -147 |
| 768 | 1 | -7.9 | 152 | -153 | 146 | -147 |
| 769 | 1 | -7.9 | 153 | -154 | 146 | -147 |
| 770 | 1 | -7.9 | 154 | -155 | 146 | -147 |
| 771 | 1 | -7.9 | 155 | -156 | 146 | -147 |
| 772 | 1 | -7.9 | 156 | -157 | 146 | -147 |
| 773 | 1 | -7.9 | 157 | -158 | 146 | -147 |
| 774 | 1 | -7.9 | 158 | -159 | 146 | -147 |
| 775 | 1 | -7.9 | 159 | -160 | 146 | -147 |
| 776 | 1 | -7.9 | 160 | -161 | 146 | -147 |
| 777 | 1 | -7.9 | 161 | -162 | 146 | -147 |
| 778 | 1 | -7.9 | 162 | -163 | 146 | -147 |
| 779 | 1 | -7.9 | 163 | -164 | 146 | -147 |
| 780 | 1 | -7.9 | 164 | -165 | 146 | -147 |
| 781 | 1 | -7.9 | 165 | -166 | 146 | -147 |
| 782 | 1 | -7.9 | 166 | -167 | 146 | -147 |
| 783 | 1 | -7.9 | 167 | -168 | 146 | -147 |
| 784 | 1 | -7.9 | 168 | -169 | 146 | -147 |
| 785 | 1 | -7.9 | 169 | -170 | 146 | -147 |
| 786 | 1 | -7.9 | 170 | -171 | 146 | -147 |
| 787 | 1 | -7.9 | 171 | -172 | 146 | -147 |
| 788 | 1 | -7.9 | 172 | -173 | 146 | -147 |
| 789 | 1 | -7.9 | 173 | -174 | 146 | -147 |
| 790 | 1 | -7.9 | 174 | -175 | 146 | -147 |
| 791 | 1 | -7.9 | 175 | -176 | 146 | -147 |
| 792 | 1 | -7.9 | 176 | -177 | 146 | -147 |
| 793 | 1 | -7.9 | 177 | -178 | 146 | -147 |
| 794 | 1 | -7.9 | 178 | -179 | 146 | -147 |
| 795 | 1 | -7.9 | 179 | -180 | 146 | -147 |
| 796 | 1 | -7.9 | 180 | -181 | 146 | -147 |
| 797 | 1 | -7.9 | 181 | -182 | 146 | -147 |
| 798 | 1 | -7.9 | 182 | -183 | 146 | -147 |
| 799 | 1 | -7.9 | 183 | -184 | 146 | -147 |
| 800 | 1 | -7.9 | 184 | -185 | 146 | -147 |
| 801 | 1 | -7.9 | 185 | -186 | 146 | -147 |
| 802 | 1 | -7.9 | 186 | -187 | 146 | -147 |
| 803 | 1 | -7.9 | 187 | -188 | 146 | -147 |
| 804 | 1 | -7.9 | 188 | -189 | 146 | -147 |

93
THE STACK

$ THE STACK
95

864   1 -7.9  260 -261 146 -147
865   1 -7.9  261 -262 146 -147
866   1 -7.9  262 -263 146 -147
867   1 -7.9  263 -264 146 -147
868   1 -7.9  264 -265 146 -147
869   1 -7.9  265 -266 146 -147
870   1 -7.9  266 -267 146 -147
871   1 -7.9  267 -268 146 -147
872   1 -7.9  268 -269 146 -147
873   1 -7.9  269 -270 146 -147
874   1 -7.9  270 -271 146 -147
875   1 -7.9  271 -272 146 -147
876   1 -7.9  272 -273 146 -147
877   1 -7.9  273 -274 146 -147
878   1 -7.9  274 -275 146 -147
879   1 -7.9  275 -276 146 -147
880   1 -7.9  276 -277 146 -147
881   1 -7.9  277 -278 146 -147
882   1 -7.9  278 -279 146 -147
883   1 -7.9  279 -280 146 -147
884   1 -7.9  280 -281 146 -147
885   1 -7.9  281 -282 146 -147
886   1 -7.9  282 -283 146 -147
887   1 -7.9  283 -284 146 -147
888   1 -7.9  284 -285 146 -147
889   1 -7.9  285 -286 146 -147
890   1 -7.9  286 -287 146 -147
891   1 -7.9  287 -288 146 -147
892   1 -7.9  288 -289 146 -147
893   1 -7.9  289 -290 146 -147
894   1 -7.9  290 -291 146 -147
895   1 -7.9  291 -292 146 -147
896   1 -7.9  292 -293 146 -147
897   1 -7.9  293 -294 146 -147
898   1 -7.9  294 -295 146 -147
899   1 -7.9  295 -296 146 -147
900   1 -7.9  296 -297 146 -147
901   1 -7.9  297 -298 146 -147
902   1 -7.9  298 -299 146 -147
903   1 -7.9  299 -300 146 -147
904   1 -7.9  300 -301 146 -147
905   1 -7.9  301 -302 146 -147
906   1 -7.9  302 -303 146 -147
907   1 -7.9  303 -304 146 -147
908   1 -7.9  304 -305 146 -147
909   1 -7.9  305 -306 146 -147
910   1 -7.9  306 -307 146 -147
911   1 -7.9  307 -308 146 -147
912   1 -7.9  308 -309 146 -147
913   1 -7.9  309 -310 146 -147
914   1 -7.9  310 -311 146 -147
915   1 -7.9  311 -312 146 -147
916   1 -7.9  312 -313 146 -147
917   1 -7.9  313 -314 146 -147
918   1 -7.9  314 -315 146 -147
919   1 -7.9  315 -316 146 -147
920   1 -7.9  316 -317 146 -147
921   1 -7.9  317 -318 146 -147
922   1 -7.9  318 -319 146 -147
923   1 -7.9  319 -320 146 -147
924   1 -7.9  320 -321 146 -147
925   1 -7.9  321 -322 146 -147
926   1 -7.9  322 -323 146 -147
927   1 -7.9  323 -324 146 -147
928   1 -7.9  324 -325 146 -147
929   1 -7.9  325 -326 146 -147
930   1 -7.9  326 -327 146 -147
931   1 -7.9  327 -328 146 -147
932   1 -7.9  328 -329 146 -147
933   1 -7.9  329 -330 146 -147
934   1 -7.9  330 -331 146 -147
935   1 -7.9  331 -332 146 -147

95
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

$ ****************************$

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

$ ****************************$

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

$ ****************************$

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

$ 10" TUNGSTEN PLUG WITH A 3" DIA HOLE
1277 0 496 -489 -137 $3"$ diameter hole thru Tungsten Plug
1278 0 668 -471 -431 $Void on inside of Pig
1279 0 679 -471 680 -147 $Void on outside of Pig

100
| 1280 | 5 | -11.34 | 499 | -498 | -461 | $ ******************************************************* |
| 1281 | 5 | -11.34 | 499 | -498 | -461 | -137 |
| 1282 | 5 | -11.34 | 498 | -497 | -461 | $ 3" Pb PLUG |
| 1283 | 5 | -11.34 | 498 | -497 | -461 | -137 |
| 1284 | 5 | -11.34 | 497 | -496 | -461 | $ ******************************************************* |
| 1285 | 5 | -11.34 | 496 | -495 | -461 | -137 |
| 1286 | 5 | -11.34 | 495 | -494 | -461 | $ 8 INCHES OF Pb |
| 1287 | 5 | -11.34 | 494 | -493 | -461 | -137 |
| 1288 | 5 | -11.34 | 493 | -492 | -461 | -137 |
| 1289 | 5 | -11.34 | 492 | -491 | -461 | -137 |
| 1290 | 5 | -11.34 | 491 | -490 | -461 | -137 |
| 1291 | 5 | -11.34 | 490 | -489 | -461 | -137 |
| 1292 | 5 | -11.34 | 489 | -488 | -461 | -137 |
| 1293 | 5 | -11.34 | 488 | -487 | -461 | -137 |
| 1294 | 5 | -11.34 | 487 | -486 | -461 | -137 |
| 1295 | 5 | -11.34 | 486 | -485 | -461 | -137 |
| 1296 | 5 | -11.34 | 485 | -484 | -461 | -137 |
| 1297 | 5 | -11.34 | 484 | -483 | -461 | -137 |
| 1298 | 5 | -11.34 | 483 | -482 | -461 | -137 |
| 1299 | 5 | -11.34 | 482 | -481 | -461 | -137 |
| 1300 | 5 | -11.34 | 481 | -480 | -461 | -137 |
| 1301 | 5 | -11.34 | 480 | -479 | -461 | -137 |
| 1302 | 5 | -11.34 | 479 | -478 | -461 | -137 |
| 1303 | 5 | -11.34 | 478 | -477 | -461 | -137 |
| 1304 | 5 | -11.34 | 477 | -476 | -461 | -137 |
| 1305 | 5 | -11.34 | 476 | -475 | -461 | -137 |
| 1306 | 5 | -11.34 | 475 | -474 | -461 | -137 |
| 1307 | 5 | -11.34 | 474 | -473 | -461 | -137 |
| 1308 | 5 | -11.34 | 473 | -472 | -461 | -137 |
| 1309 | 5 | -11.34 | 472 | -471 | -461 | -137 |
| 1310 | 5 | -11.34 | 471 | -470 | -461 | -137 |
| 1311 | 5 | -11.34 | 470 | -469 | -461 | -137 |
| 1312 | 5 | -11.34 | 469 | -468 | -461 | -137 |
| 1313 | 5 | -11.34 | 468 | -467 | -461 | -137 |
| 1314 | 5 | -11.34 | 467 | -466 | -461 | -137 |
| 1315 | 5 | -11.34 | 466 | -465 | -461 | -137 |
| 1316 | 5 | -11.34 | 465 | -464 | -461 | -137 |
| 1317 | 5 | -11.34 | 464 | -463 | -461 | -137 |
| 1318 | 5 | -11.34 | 463 | -462 | -461 | -137 |
| 1319 | 5 | -11.34 | 462 | -461 | -461 | -137 |
| 1320 | 5 | -11.34 | 461 | -460 | -461 | -137 |
| 1321 | 5 | -11.34 | 460 | -459 | -461 | -137 |
| 1322 | 5 | -11.34 | 459 | -458 | -461 | -137 |
| 1323 | 5 | -11.34 | 458 | -457 | -461 | -137 |
| 1324 | 5 | -11.34 | 457 | -456 | -461 | -137 |
| 1325 | 5 | -11.34 | 456 | -455 | -461 | -137 |
| 1326 | 5 | -11.34 | 455 | -454 | -461 | -137 |
| 1327 | 5 | -11.34 | 454 | -453 | -461 | -137 |
| 1328 | 5 | -11.34 | 453 | -452 | -461 | -137 |
| 1329 | 5 | -11.34 | 452 | -451 | -461 | -137 |
| 1330 | 5 | -11.34 | 451 | -450 | -461 | -137 |
| 1331 | 5 | -11.34 | 450 | -449 | -461 | -137 |
| 1332 | 5 | -11.34 | 449 | -448 | -461 | -137 |
| 1333 | 5 | -11.34 | 448 | -447 | -461 | -137 |
| 1334 | 5 | -11.34 | 447 | -446 | -461 | -137 |
| 1335 | 5 | -11.34 | 446 | -445 | -461 | -137 |

| 1336 | 5 | -11.34 | 445 | -444 | -461 | -137 |
| 1337 | 5 | -11.34 | 444 | -443 | -461 | -137 |
| 1338 | 5 | -11.34 | 443 | -442 | -461 | -137 |
| 1339 | 5 | -11.34 | 442 | -441 | -461 | -137 |
| 1340 | 5 | -11.34 | 441 | -440 | -461 | -137 |
| 1341 | 5 | -11.34 | 440 | -439 | -461 | -137 |
| 1342 | 5 | -11.34 | 439 | -438 | -461 | -137 |
| 1343 | 5 | -11.34 | 438 | -437 | -461 | -137 |
| 1344 | 5 | -11.34 | 437 | -436 | -461 | -137 |

| 1336 | 0 | 504 | -499 | 782 | -147 | $ ******************************************************* |
| 1337 | 0 | 504 | -499 | 782 | -147 | $ 8 INCHES OF Pb |
| 1338 | 0 | 504 | -499 | 782 | -147 |
| 1339 | 0 | 504 | -499 | 782 | -147 |
| 1340 | 0 | 504 | -499 | 782 | -147 |
| 1341 | 0 | 504 | -499 | 782 | -147 |
| 1342 | 0 | 504 | -499 | 782 | -147 |
| 1343 | 0 | 504 | -499 | 782 | -147 |
| 1344 | 0 | 504 | -499 | 782 | -147 |

101
c 1345 5 -11.34 462 -463 433 -508
 1346 5 -11.34 463 -464 433 -508
 1347 5 -11.34 464 -465 433 -508
 1348 5 -11.34 465 -466 433 -508
 1349 5 -11.34 466 -467 433 -508
 1350 5 -11.34 467 -468 433 -508
 1351 5 -11.34 468 -469 433 -508
 1352 5 -11.34 469 -470 433 -508
 1353 5 -11.34 470 -471 433 -508
 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
 1363 5 -11.34 480 -481 433 -508
 1364 5 -11.34 481 -482 433 -508
 1365 5 -11.34 482 -483 433 -508
 1366 5 -11.34 483 -484 433 -508
 1367 5 -11.34 484 -485 433 -508
 1368 5 -11.34 485 -486 433 -508
 1369 5 -11.34 486 -487 433 -508
 1370 5 -11.34 487 -488 433 -508
 1371 5 -11.34 488 -489 433 -508
 1372 5 -11.34 489 -490 433 -508
 1373 5 -11.34 490 -491 433 -508
 1374 5 -11.34 491 -492 433 -508
 1375 5 -11.34 492 -493 433 -508
 1376 5 -11.34 493 -494 433 -508
 1377 5 -11.34 494 -495 433 -508
 1378 5 -11.34 495 -496 433 -508
 1379 5 -11.34 496 -497 433 -508
 1380 5 -11.34 497 -498 433 -508
 1381 5 -11.34 498 -499 433 -508
 1382 5 -11.34 499 -500 433 -508
 1383 5 -11.34 500 -501 433 -508
 1384 5 -11.34 501 -502 433 -508
 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 -481 508 -509
 1393 1 -7.9 462 -463 508 -509
 1394 1 -7.9 463 -464 508 -509
 1395 1 -7.9 464 -465 508 -509
 1396 1 -7.9 465 -466 508 -509
 1397 1 -7.9 466 -467 508 -509
 1398 1 -7.9 467 -468 508 -509
 1399 1 -7.9 468 -469 508 -509
 1400 1 -7.9 469 -470 508 -509
 1401 1 -7.9 470 -471 508 -509
 1402 1 -7.9 471 -472 508 -509
 1403 1 -7.9 472 -473 508 -509
 1404 1 -7.9 473 -474 508 -509
 1405 1 -7.9 474 -475 508 -509
 1406 1 -7.9 475 -476 508 -509
 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 -482 508 -509
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
1417 1 -7.9 438 -439 508 -509
1418 1 -7.9 439 -440 508 -509
1419 1 -7.9 440 -441 508 -509
1420 1 -7.9 441 -442 508 -509
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 -446 508 -509
1425 1 -7.9 446 -447 508 -509
1426 1 -7.9 447 -448 508 -509
1427 1 -7.9 448 -449 508 -509
1428 1 -7.9 449 -450 508 -509
1429 1 -7.9 450 -451 508 -509
1430 1 -7.9 451 -452 508 -509
1431 1 -7.9 452 -453 508 -509
1432 1 -7.9 453 -454 508 -509
1433 0 499 -498 508 -147
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
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
1453 0 32 -46 758 -23
1454 0 32 -46 758 -23
1455 0 32 -46 758 -23
1456 0 32 -46 758 -23
1457 0 32 -46 758 -23
1458 0 32 -46 758 -23
1459 0 32 -46 758 -23
1460 0 32 -46 758 -23
1461 0 32 -46 758 -23
1462 0 32 -46 758 -23
1463 0 32 -46 758 -23
1464 0 32 -46 758 -23
1465 0 32 -46 758 -23
1466 0 32 -46 758 -23
1467 0 32 -46 758 -23
1468 0 32 -46 758 -23
1469 0 32 -46 758 -23
1470 0 32 -46 758 -23
1471 0 32 -46 758 -23
1472 0 32 -46 758 -23
1473 0 32 -46 758 -23
1474 0 32 -46 758 -23
1475 0 32 -46 758 -23
1476 0 32 -46 758 -23
1477 0 32 -46 758 -23
1478 0 32 -46 758 -23
1479 0 32 -46 758 -23
1480 0 32 -46 758 -23
1481 0 32 -46 758 -23
1482 0 32 -46 758 -23
1483 0 32 -46 758 -23
1484 0 32 -46 758 -23
1485 0 32 -46 758 -23
1486 0 32 -46 758 -23
1487 0 32 -46 758 -23
1488 0 32 -46 758 -23
1489 0 32 -46 758 -23
1490 0 32 -46 758 -23
1491 0 32 -46 758 -23
1492 0 32 -46 758 -23
1493 0 32 -46 758 -23
1494 0 32 -46 758 -23
1495 0 32 -46 758 -23
1496 0 32 -46 758 -23
1497 0 32 -46 758 -23
1498 0 32 -46 758 -23
1499 0 32 -46 758 -23
1500 1 -7.9 600 -148 610 -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
<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1525</td>
<td>1</td>
<td>-7.9</td>
<td>600</td>
<td>-148</td>
<td>626 -625</td>
</tr>
<tr>
<td>1526</td>
<td>1</td>
<td>-7.9</td>
<td>600</td>
<td>-148</td>
<td>627 -626</td>
</tr>
<tr>
<td>1527</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>628</td>
<td>-627</td>
</tr>
<tr>
<td>1528</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>629</td>
<td>-628</td>
</tr>
<tr>
<td>1529</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>630</td>
<td>-629</td>
</tr>
<tr>
<td>1530</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>631</td>
<td>-630</td>
</tr>
<tr>
<td>1531</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>632</td>
<td>-631</td>
</tr>
<tr>
<td>1532</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>633</td>
<td>-632</td>
</tr>
<tr>
<td>1533</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>634</td>
<td>-633</td>
</tr>
<tr>
<td>1534</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>635</td>
<td>-634</td>
</tr>
<tr>
<td>1535</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>636</td>
<td>-635</td>
</tr>
<tr>
<td>1536</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>637</td>
<td>-636</td>
</tr>
<tr>
<td>1537</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>638</td>
<td>-637</td>
</tr>
<tr>
<td>1538</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>639</td>
<td>-638</td>
</tr>
<tr>
<td>1539</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>640</td>
<td>-639</td>
</tr>
<tr>
<td>1540</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>641</td>
<td>-640</td>
</tr>
<tr>
<td>1541</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>642</td>
<td>-641</td>
</tr>
<tr>
<td>1542</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>643</td>
<td>-642</td>
</tr>
<tr>
<td>1543</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>644</td>
<td>-643</td>
</tr>
<tr>
<td>1544</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>645</td>
<td>-644</td>
</tr>
<tr>
<td>1545</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>646</td>
<td>-645</td>
</tr>
<tr>
<td>1546</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>647</td>
<td>-646</td>
</tr>
<tr>
<td>1547</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>648</td>
<td>-647</td>
</tr>
<tr>
<td>1548</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>649</td>
<td>-648</td>
</tr>
<tr>
<td>1549</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>759</td>
<td>-649</td>
</tr>
<tr>
<td>1550</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>758</td>
<td>-759</td>
</tr>
<tr>
<td>1551</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>757</td>
<td>-758</td>
</tr>
<tr>
<td>1552</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>756</td>
<td>-757</td>
</tr>
<tr>
<td>1553</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>755</td>
<td>-756</td>
</tr>
<tr>
<td>1554</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>754</td>
<td>-755</td>
</tr>
<tr>
<td>1555</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>753</td>
<td>-754</td>
</tr>
<tr>
<td>1556</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>752</td>
<td>-753</td>
</tr>
<tr>
<td>1557</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>751</td>
<td>-752</td>
</tr>
<tr>
<td>1558</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>750</td>
<td>-751</td>
</tr>
<tr>
<td>1559</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>749</td>
<td>-750</td>
</tr>
<tr>
<td>1560</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>748</td>
<td>-749</td>
</tr>
<tr>
<td>1561</td>
<td>0</td>
<td>600</td>
<td>-148</td>
<td>665</td>
<td>-748</td>
</tr>
</tbody>
</table>

$ END OF BOTTOM LID

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

$ END OF BOTTOM LID

$ 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  $ 3 INCH RADIUS VOIED
1597 8 -7.84 148 -662 749 -750
1598 8 -7.84 148 -662 748 -749
1599 8 -7.84 148 -662 665 -748

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 -600 650 -649
1623 8 -7.84 664 -600 651 -650
1624 8 -7.84 664 -600 652 -651
1625 8 -7.84 664 -600 653 -652
1626 8 -7.84 664 -600 654 -653
1627 8 -7.84 664 -600 655 -654
1628 8 -7.84 664 -600 656 -655
1629 8 -7.84 664 -600 657 -656
1630 8 -7.84 664 -600 658 -657
1631 8 -7.84 664 -600 659 -658
1632 8 -7.84 664 -600 660 -659
1633 8 -7.84 664 -600 661 -660
1634 8 -7.84 664 -600 662 -661  $ END OF 1/2" SHIELD PLATE

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 **

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

1641 0 662 -507 -147  $ VOID B/W AIR SIDE OF LID TO TOP OF 8" Pb

1642 6 -1.032 666 -667 -137  $ TOP nTOF SCINTILLATOR

1643 7 -2.7 489 -666 -137  $ 1/8" ALUMINUM (DETECTOR HOUSING)
1644 7 -2.7 667 -668 -137  $ 1/8" ALUMINUM (DETECTOR HOUSING)

1645 0 489 -668 935 -431  $ VOID AROUND TOP nTOF INSIDE PIG

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

1649 0 662 -663 -763  $ 8" FLANGE (nTOF SEE THRU)
1650 0 662 -663 767 -147

1651 7 -2.7 489 -670 137 -935  $ TOP nTOF ALUMINUM HOUSING
1652  7  -2.7  670 -668  137  -935  $ TOP nTOF ALUMINUM HOUSING

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

1657  0  10  -13  -25  $ VOID B/L BOTTOM BLAST SHIELD

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  $ "    "    "    "    "

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 -630

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  650 -649

1685  4  -8.96  675 -664  651 -650

1686  4  -8.96  675 -664  652 -651

1687  4  -8.96  675 -664  653 -652

1688  4  -8.96  675 -664  654 -653

1689  4  -8.96  675 -664  655 -654

1690  4  -8.96  675 -664  656 -655

1691  4  -8.96  675 -664  657 -656

1692  4  -8.96  675 -664  658 -657

1693  4  -8.96  675 -664  659 -658

1694  4  -8.96  675 -664  660 -659

1695  4  -8.96  675 -664  661 -660

1696  4  -8.96  675 -664  662 -661

1697  4  -8.96  675 -664  663  $ 9/16" COPPER SHIELD PLATE

1698  0  675 -664  624 -146

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  $ "    "    "    "

1705  8  -7.84  676 -677  -760  $ ELEVATOR FLOOR

1706  8  -7.84  676 -677  760 -761

1707  8  -7.84  676 -677  761 -764

1708  8  -7.84  676 -677  764 -767

1709  8  -7.84  676 -677  767 -769

1710  8  -7.84  676 -677  769 -770

1711  8  -7.84  676 -677  770 -771

1712  8  -7.84  676 -677  771 -772

1713  8  -7.84  676 -677  772 -773

106
| 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 | 757 | -758 |
| 1718 | 8 | -7.84 | 676 | -677 | 762 | -757 |
| 1719 | 8 | -7.84 | 676 | -677 | 757 | -758 |
| 1720 | 8 | -7.84 | 676 | -677 | 758 | -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$

$ VOID B/W BOTTOM OF PIG AND ELEVATOR FLOOR$
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
1908  9 -0.915 690 -689 -137 692
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
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
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
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
<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>9</td>
<td>-0.915 700 -699 -451 692</td>
</tr>
<tr>
<td>1964</td>
<td>9</td>
<td>-0.915 700 -699 -450 692</td>
</tr>
<tr>
<td>1965</td>
<td>9</td>
<td>-0.915 700 -699 -137 692</td>
</tr>
<tr>
<td>1966</td>
<td>9</td>
<td>-0.915 701 -700 -454 453</td>
</tr>
<tr>
<td>1967</td>
<td>9</td>
<td>-0.915 701 -744 -453 692</td>
</tr>
<tr>
<td>1968</td>
<td>9</td>
<td>-0.915 744 -700 -453 692</td>
</tr>
<tr>
<td>1969</td>
<td>9</td>
<td>-0.915 701 -700 -451 692</td>
</tr>
<tr>
<td>1970</td>
<td>9</td>
<td>-0.915 701 -700 -450 692</td>
</tr>
<tr>
<td>1971</td>
<td>9</td>
<td>-0.915 701 -700 -137 692</td>
</tr>
<tr>
<td>1972</td>
<td>9</td>
<td>-0.915 702 -701 -454 453</td>
</tr>
<tr>
<td>1973</td>
<td>9</td>
<td>-0.915 702 -743 -453 692</td>
</tr>
<tr>
<td>1974</td>
<td>9</td>
<td>-0.915 743 -701 -453 692</td>
</tr>
<tr>
<td>1975</td>
<td>9</td>
<td>-0.915 702 -701 -451 692</td>
</tr>
<tr>
<td>1976</td>
<td>9</td>
<td>-0.915 702 -701 -450 692</td>
</tr>
<tr>
<td>1977</td>
<td>9</td>
<td>-0.915 702 -701 -137 692</td>
</tr>
<tr>
<td>1978</td>
<td>9</td>
<td>-0.915 703 -702 -454 453</td>
</tr>
<tr>
<td>1979</td>
<td>9</td>
<td>-0.915 703 -742 -453 692</td>
</tr>
<tr>
<td>1980</td>
<td>9</td>
<td>-0.915 742 -702 -453 692</td>
</tr>
<tr>
<td>1981</td>
<td>9</td>
<td>-0.915 703 -702 -451 692</td>
</tr>
<tr>
<td>1982</td>
<td>9</td>
<td>-0.915 703 -702 -450 692</td>
</tr>
<tr>
<td>1983</td>
<td>9</td>
<td>-0.915 703 -702 -137 692</td>
</tr>
<tr>
<td>1984</td>
<td>9</td>
<td>-0.915 704 -703 -454 453</td>
</tr>
<tr>
<td>1985</td>
<td>9</td>
<td>-0.915 704 -741 -453 692</td>
</tr>
<tr>
<td>1986</td>
<td>9</td>
<td>-0.915 741 -703 -453 692</td>
</tr>
<tr>
<td>1987</td>
<td>9</td>
<td>-0.915 704 -703 -451 692</td>
</tr>
<tr>
<td>1988</td>
<td>9</td>
<td>-0.915 704 -703 -450 692</td>
</tr>
<tr>
<td>1989</td>
<td>9</td>
<td>-0.915 704 -703 -137 692</td>
</tr>
<tr>
<td>1990</td>
<td>9</td>
<td>-0.915 705 -704 -454 453</td>
</tr>
<tr>
<td>1991</td>
<td>9</td>
<td>-0.915 705 -740 -453 692</td>
</tr>
<tr>
<td>1992</td>
<td>9</td>
<td>-0.915 740 -704 -453 692</td>
</tr>
<tr>
<td>1993</td>
<td>9</td>
<td>-0.915 705 -704 -451 692</td>
</tr>
<tr>
<td>1994</td>
<td>9</td>
<td>-0.915 705 -704 -450 692</td>
</tr>
<tr>
<td>1995</td>
<td>9</td>
<td>-0.915 705 -704 -137 692</td>
</tr>
<tr>
<td>1996</td>
<td>9</td>
<td>-0.915 706 -705 -454 453</td>
</tr>
<tr>
<td>1997</td>
<td>9</td>
<td>-0.915 706 -739 -453 692</td>
</tr>
<tr>
<td>1998</td>
<td>9</td>
<td>-0.915 739 -705 -453 692</td>
</tr>
<tr>
<td>1999</td>
<td>9</td>
<td>-0.915 706 -705 -451 692</td>
</tr>
<tr>
<td>2000</td>
<td>9</td>
<td>-0.915 706 -705 -450 692</td>
</tr>
<tr>
<td>2001</td>
<td>9</td>
<td>-0.915 706 -705 -137 692</td>
</tr>
<tr>
<td>2002</td>
<td>9</td>
<td>-0.915 707 -706 -454 453</td>
</tr>
<tr>
<td>2003</td>
<td>9</td>
<td>-0.915 707 -738 -453 692</td>
</tr>
<tr>
<td>2004</td>
<td>9</td>
<td>-0.915 738 -706 -453 692</td>
</tr>
<tr>
<td>2005</td>
<td>9</td>
<td>-0.915 707 -706 -451 692</td>
</tr>
<tr>
<td>2006</td>
<td>9</td>
<td>-0.915 707 -706 -450 692</td>
</tr>
<tr>
<td>2007</td>
<td>9</td>
<td>-0.915 707 -706 -137 692</td>
</tr>
<tr>
<td>2008</td>
<td>9</td>
<td>-0.915 708 -707 -454 453</td>
</tr>
<tr>
<td>2009</td>
<td>9</td>
<td>-0.915 708 -737 -453 692</td>
</tr>
<tr>
<td>2010</td>
<td>9</td>
<td>-0.915 737 -707 -453 692</td>
</tr>
<tr>
<td>2011</td>
<td>9</td>
<td>-0.915 708 -707 -451 692</td>
</tr>
<tr>
<td>2012</td>
<td>9</td>
<td>-0.915 708 -707 -450 692</td>
</tr>
<tr>
<td>2013</td>
<td>9</td>
<td>-0.915 708 -707 -137 692</td>
</tr>
<tr>
<td>2014</td>
<td>9</td>
<td>-0.915 709 -708 -454 453</td>
</tr>
<tr>
<td>2015</td>
<td>9</td>
<td>-0.915 709 -736 -453 692</td>
</tr>
<tr>
<td>2016</td>
<td>9</td>
<td>-0.915 736 -708 -453 692</td>
</tr>
</tbody>
</table>
2017 9 -0.915 709 -708 -451 692
2018 9 -0.915 709 -708 -450 692
2019 9 -0.915 709 -708 -137 692
2020 9 -0.915 710 -709 -454 453
2021 9 -0.915 710 -723 -453 692
2022 9 -0.915 723 -709 -453 692
2023 9 -0.915 710 -709 -451 692
2024 9 -0.915 710 -709 -450 692
2025 9 -0.915 710 -709 -137 692
2026 9 -0.915 711 -710 -454 453
2027 9 -0.915 711 -724 -453 692
2028 9 -0.915 724 -710 -453 692
2029 9 -0.915 711 -710 -451 692
2030 9 -0.915 711 -710 -450 692
2031 9 -0.915 711 -710 -137 692
2032 9 -0.915 712 -711 -454 453
2033 9 -0.915 712 -725 -453 692
2034 9 -0.915 725 -711 -453 692
2035 9 -0.915 712 -711 -451 692
2036 9 -0.915 712 -711 -450 692
2037 9 -0.915 712 -711 -137 692
2038 9 -0.915 713 -712 -454 453
2039 9 -0.915 713 -726 -453 692
2040 9 -0.915 726 -712 -453 692
2041 9 -0.915 713 -712 -451 692
2042 9 -0.915 713 -712 -450 692
2043 9 -0.915 713 -712 -137 692
2044 9 -0.915 714 -713 -454 453
2045 9 -0.915 714 -727 -453 692
2046 9 -0.915 727 -713 -453 692
2047 9 -0.915 714 -713 -451 692
2048 9 -0.915 714 -713 -450 692
2049 9 -0.915 714 -713 -137 692
2050 9 -0.915 715 -714 -454 453
2051 9 -0.915 715 -728 -453 692
2052 9 -0.915 728 -714 -453 692
2053 9 -0.915 715 -714 -451 692
2054 9 -0.915 715 -714 -450 692
2055 9 -0.915 715 -714 -137 692
2056 9 -0.915 716 -715 -454 453
2057 9 -0.915 716 -729 -453 692
2058 9 -0.915 729 -715 -453 692
2059 9 -0.915 716 -715 -451 692
2060 9 -0.915 716 -715 -450 692
2061 9 -0.915 716 -715 -137 692
2062 9 -0.915 717 -716 -454 453
2063 9 -0.915 717 -730 -453 692
2064 9 -0.915 730 -716 -453 692
2065 9 -0.915 717 -716 -451 692
2066 9 -0.915 717 -716 -450 692
2067 9 -0.915 717 -716 -137 692
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 2071  9  -0.915  718  -717  -451  692
c 2072  9  -0.915  718  -717  -450  692
2073  9  -0.915  718  -717  -137  692
2074  9  -0.915  719  -718  -454  453
2075  9  -0.915  719  -718  -450  692
2076  9  -0.915  719  -718  -137  692
2077  9  -0.915  719  -718  -451  692
2078  9  -0.915  719  -718  -450  692
2079  9  -0.915  719  -718  -137  692
2080  9  -0.915  720  -719  -454  453
2081  9  -0.915  720  -719  -453  692
2082  9  -0.915  720  -719  -453  692
2083  9  -0.915  720  -719  -451  692
2084  9  -0.915  720  -719  -450  692
2085  9  -0.915  720  -719  -137  692
2086  9  -0.915  720  -719  -454  452
2087  9  -0.915  720  -720  -451  692
2088  9  -0.915  720  -720  -452  451
2089  9  -0.915  721  -720  -451  692
2090  9  -0.915  721  -720  -450  692
2091  9  -0.915  721  -720  -137  692
2092  9  -0.915  722  -721  -454  453
2093  9  -0.915  722  -721  -453  692
2094  9  -0.915  722  -721  -453  692
2095  9  -0.915  722  -721  -451  692
2096  9  -0.915  722  -721  -450  692
2097  9  -0.915  722  -721  -137  692
2098  0  734  -504  -692  $ VOID INSIDE POLY
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
2110  0  716  -739  455  -147
2111  1  -7.9  -799  #1771  $ 16" DIA SS PLATE
2112  1  -7.9  784  -785  760  -761  $ 1/2" PLATE OF PIG
2113  1  -7.9  784  -785  761  -748  $ (WHERE YOKE SWIVELS)
2114  1  -7.9  784  -785  748  -749
2115  1  -7.9  784  -785  749  -750
2116  1  -7.9  784  -785  750  -751
2117  1  -7.9  784  -785  751  -752
2118  1  -7.9  784  -785  752  -753
2119  1  -7.9  784  -785  753  -754
2120  0  784  -785  799  -147  #1826 #1874 #2287 #2288 #2286
2121  8  -7.84  785  -786  -760  $ 1/2" PLATE OF PIG
2122  8  -7.84  785  -786  760  -761  $ CHASSIS
2123  8  -7.84  785  -786  761  -748
2124  8  -7.84  785  -786  748  -749
2125  8  -7.84  785  -786  749  -750
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 -757

c 2133 8 -7.84 785 -786 757 -758

c 2134 8 -7.84 785 -786 758 -759

c 2135 8 -7.84 785 -786 759 -762

c 2136 8 -7.84 785 -786 762 -757

c 2137 8 -7.84 785 -786 757 -758

c 2138 8 -7.84 785 -786 758 -759

c 2139 8 -7.84 785 -786 759 -649

c 2140 8 -7.84 785 -786 649 -648

c 2141 8 -7.84 785 -786 648 -647

c 2142 8 -7.84 785 -786 647 -646

c 2143 8 -7.84 785 -786 646 -645

c 2144 0 785 -786 792 -147 #2288 #2286 #2287

c 2145 0 786 -786 -147 #1874 #2286 $ #2144

c 2146 8 -7.84 785 -786 642 -641

c 2147 9 -0.915 500 -499 780 -781 $ BEGINNING OF 30.5" DIA

c 2148 9 -0.915 500 -499 508 -780 $ BORATED POLY PIECE (RIGHT

c 2149 9 -0.915 500 -499 433 -508 $ NOW, IT'S JUST POLY

c 2150 9 -0.915 500 -499 458 -433 $ AROUND Pb, RESTING ON TOP

c 2151 9 -0.915 500 -499 458 -432 $ OF PIG

c 2152 9 -0.915 500 -499 457 -432

c 2153 9 -0.915 500 -499 456 -432

c 2154 9 -0.915 500 -499 455 -432

c 2155 9 -0.915 500 -499 454 -453

c 2156 9 -0.915 501 -500 780 -781

c 2157 9 -0.915 501 -500 508 -780

c 2158 9 -0.915 501 -500 433 -508

c 2159 9 -0.915 501 -500 432 -433

c 2160 9 -0.915 501 -500 458 -432

c 2161 9 -0.915 501 -500 457 -458

c 2162 9 -0.915 501 -500 456 -457

c 2163 9 -0.915 501 -500 455 -456

c 2164 9 -0.915 501 -500 454 -455

c 2165 9 -0.915 502 -501 780 -781

c 2166 9 -0.915 502 -501 508 -780

c 2167 9 -0.915 502 -501 433 -508

c 2168 9 -0.915 502 -501 432 -433

c 2169 9 -0.915 502 -501 458 -432

c 2170 9 -0.915 502 -501 457 -458

c 2171 9 -0.915 502 -501 456 -457

c 2172 9 -0.915 502 -501 455 -456

c 2173 9 -0.915 502 -501 454 -455

c 2174 9 -0.915 503 -502 780 -781

c 2175 9 -0.915 503 -502 508 -780

c 2176 9 -0.915 503 -502 433 -508

c 2177 9 -0.915 503 -502 432 -433

c 2178 9 -0.915 503 -502 458 -432

c 2179 9 -0.915 503 -502 457 -458

c 2180 9 -0.915 503 -502 456 -457

c 2181 9 -0.915 503 -502 455 -456

c 2182 9 -0.915 503 -502 454 -455

c 2183 9 -0.915 504 -503 780 -781

c 2184 9 -0.915 504 -503 508 -780

c 2185 9 -0.915 504 -503 433 -508

c 2186 9 -0.915 504 -503 432 -433

c 2187 9 -0.915 504 -503 431 -432

c 2188 9 -0.915 504 -503 458 -457

c 2189 9 -0.915 504 -503 456 -457

c 2190 9 -0.915 504 -503 455 -456

c 2191 9 -0.915 504 -503 454 -455

c 2192 9 -0.915 504 -503 781 -782

c 2193 9 -0.915 503 -502 781 -782

c 2194 9 -0.915 502 -501 781 -782
$ END OF 30.5" DIA POLY

$ BEGINNING OF 2, 2FT DIA PIECES OF POLY ON TOP OF Pb

...
<table>
<thead>
<tr>
<th>Row</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2264</td>
<td>9 -0.915</td>
<td>700 -699</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2265</td>
<td>9 -0.915</td>
<td>700 -699</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2266</td>
<td>9 -0.915</td>
<td>701 -700</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2267</td>
<td>9 -0.915</td>
<td>701 -700</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2268</td>
<td>9 -0.915</td>
<td>702 -701</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2269</td>
<td>9 -0.915</td>
<td>702 -701</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2270</td>
<td>9 -0.915</td>
<td>702 -701</td>
<td>454 -455</td>
<td></td>
</tr>
<tr>
<td>2271</td>
<td>9 -0.915</td>
<td>703 -702</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2272</td>
<td>9 -0.915</td>
<td>703 -702</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2273</td>
<td>9 -0.915</td>
<td>703 -702</td>
<td>454 -455</td>
<td></td>
</tr>
<tr>
<td>2274</td>
<td>9 -0.915</td>
<td>704 -703</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2275</td>
<td>9 -0.915</td>
<td>704 -703</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2276</td>
<td>9 -0.915</td>
<td>704 -703</td>
<td>454 -455</td>
<td></td>
</tr>
<tr>
<td>2277</td>
<td>9 -0.915</td>
<td>705 -704</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2278</td>
<td>9 -0.915</td>
<td>705 -704</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2279</td>
<td>9 -0.915</td>
<td>705 -704</td>
<td>454 -455</td>
<td></td>
</tr>
<tr>
<td>2280</td>
<td>9 -0.915</td>
<td>706 -705</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2281</td>
<td>9 -0.915</td>
<td>706 -705</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2282</td>
<td>9 -0.915</td>
<td>706 -705</td>
<td>454 -455</td>
<td></td>
</tr>
<tr>
<td>2283</td>
<td>9 -0.915</td>
<td>707 -706</td>
<td>456 -457</td>
<td></td>
</tr>
<tr>
<td>2284</td>
<td>9 -0.915</td>
<td>707 -706</td>
<td>455 -456</td>
<td></td>
</tr>
<tr>
<td>2285</td>
<td>0 739 -695</td>
<td>457 -147</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2286</td>
<td>8 -7.84</td>
<td>-792 $ #2120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2287</td>
<td>8 -7.84</td>
<td>-793 #2286 #2145 #2290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2288</td>
<td>8 -7.84</td>
<td>-794 #2286 #2145 #2292</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2289</td>
<td>8 -7.84</td>
<td>-795 #2290</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2290</td>
<td>8 -7.84</td>
<td>-796</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2291</td>
<td>8 -7.84</td>
<td>-797 #2292</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2292</td>
<td>8 -7.84</td>
<td>-798</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2293</td>
<td>8 -7.84</td>
<td>-800 801</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2294</td>
<td>0 -801</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2295</td>
<td>1 -7.9</td>
<td>-1 900 23 -22 $ INNER MITL EXTENSION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2296</td>
<td>1 -7.9</td>
<td>-900 901 23 -22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2297</td>
<td>1 -7.9</td>
<td>-901 902 23 -22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2298</td>
<td>1 -7.9</td>
<td>-902 903 23 -22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2299</td>
<td>1 -7.9</td>
<td>-903 904 23 -22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2300</td>
<td>1 -7.9</td>
<td>-904 905 23 -22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2301</td>
<td>0 144 -146 -1 909</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2302</td>
<td>0 -928 26 -147</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2303</td>
<td>1 -7.9</td>
<td>-1 900 -144 143 $ OUTER MITL EXTENSION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2304</td>
<td>1 -7.9</td>
<td>-900 901 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2305</td>
<td>1 -7.9</td>
<td>-901 902 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2306</td>
<td>1 -7.9</td>
<td>-902 903 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2307</td>
<td>1 -7.9</td>
<td>-903 904 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2308</td>
<td>1 -7.9</td>
<td>-904 905 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2309</td>
<td>1 -7.9</td>
<td>-905 906 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2310</td>
<td>1 -7.9</td>
<td>-906 907 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2311</td>
<td>1 -7.9</td>
<td>-907 908 -144 143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2312</td>
<td>1 -7.9</td>
<td>-1 900 -147 146 $ EXTENSION OF STACK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2313</td>
<td>1 -7.9</td>
<td>-900 901 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2314</td>
<td>1 -7.9</td>
<td>-901 902 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2315</td>
<td>1 -7.9</td>
<td>-902 903 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2316</td>
<td>1 -7.9</td>
<td>-903 904 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2317</td>
<td>1 -7.9</td>
<td>-904 905 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2318</td>
<td>1 -7.9</td>
<td>-905 906 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2319</td>
<td>1 -7.9</td>
<td>-906 907 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2320</td>
<td>1 -7.9</td>
<td>-907 908 -147 146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2321</td>
<td>1 -7.9</td>
<td>-909 908 144 -752</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2322</td>
<td>1 -7.9</td>
<td>-909 908 752 -753</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2323</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2324</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2325</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2326</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2327</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2328</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2329</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2330</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2331</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2332</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2333</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2334</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2335</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2336</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2337</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2338</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2339</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2340</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2341</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2342</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2343</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2344</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2345</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2346</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2347</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2348</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2349</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2350</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2351</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2352</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2353</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2354</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2355</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2356</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2357</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2358</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2359</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2360</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2361</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2362</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2363</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2364</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2365</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2366</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2367</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2368</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2369</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2370</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2371</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2372</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2373</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2374</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2375</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2376</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2377</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2378</td>
<td>1</td>
<td>-7.9</td>
<td>-909</td>
<td>908</td>
</tr>
<tr>
<td>2379</td>
<td>0</td>
<td>-905</td>
<td>908</td>
<td>-22</td>
</tr>
</tbody>
</table>
| 2380 | 1 | -7.9 | 754 | -926 | -908 | 910 | $ DEBRIS SHIELD (1/2" THICK SS)$
COPPER LID ON DEBRIS SHIELD

RINGS ON TOP OF DEBRIS SHIELD

VOID INSIDE DEBRIS SHIELD

EXTENSION OF STACK TO TOP OF DEBRIS SHIELD

LOCATION OF SOURCE

OUTSIDE MACHINE

UNIVERSE OUTSIDE -- KILL ZONE

COOKIE-CUTTER CELL

Universe outside -- Kill Zone

**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

118
2.5" hole thru top SS plate

Outer MITL Cone

Inner MITL Cone

Collimator Cone

Plane above Debris Shield
127.6096 $ OUTER DIA OF SCINTILLATOR
128.8796
130.1496
131.4196
132.6896
133.9596
135.2296
136.4996
137.7696
139.0396
140.3096
141.5796
142.8496
144.1196
145.3896
146.6596
147.9296
149.1996
150.0632 $ OUTER DIA OF SCINTILLATOR
3.81 $ Cone for space b/w TIVAR & MITL
18.0 $ TIVAR cone to shadow pig to twice it's radius
0.64 $ Inner MITL Cone #2
0.6780965 $ Outer MITL Cone #2
0.6780965 $ Base of MITL Cone #2
5' 3'' $ Radius of Stack
1" thick $ Outer radius of stack
$ Bottom of Stack
$ Bottom of MITL #1 Cylinder
<table>
<thead>
<tr>
<th></th>
<th>py</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>py</td>
<td>151.3332</td>
</tr>
<tr>
<td>151</td>
<td>py</td>
<td>152.6032</td>
</tr>
<tr>
<td>152</td>
<td>py</td>
<td>153.8732</td>
</tr>
<tr>
<td>153</td>
<td>py</td>
<td>155.1432</td>
</tr>
<tr>
<td>154</td>
<td>py</td>
<td>156.4132</td>
</tr>
<tr>
<td>155</td>
<td>py</td>
<td>157.6832</td>
</tr>
<tr>
<td>156</td>
<td>py</td>
<td>158.9532</td>
</tr>
<tr>
<td>157</td>
<td>py</td>
<td>160.2232</td>
</tr>
<tr>
<td>158</td>
<td>py</td>
<td>161.4932</td>
</tr>
<tr>
<td>159</td>
<td>py</td>
<td>162.7632</td>
</tr>
<tr>
<td>160</td>
<td>py</td>
<td>164.0332</td>
</tr>
<tr>
<td>161</td>
<td>py</td>
<td>165.3032</td>
</tr>
<tr>
<td>162</td>
<td>py</td>
<td>166.5732</td>
</tr>
<tr>
<td>163</td>
<td>py</td>
<td>167.8432</td>
</tr>
<tr>
<td>164</td>
<td>py</td>
<td>169.1132</td>
</tr>
<tr>
<td>165</td>
<td>py</td>
<td>170.3832</td>
</tr>
<tr>
<td>166</td>
<td>py</td>
<td>171.6532</td>
</tr>
<tr>
<td>167</td>
<td>py</td>
<td>172.9232</td>
</tr>
<tr>
<td>168</td>
<td>py</td>
<td>174.1932</td>
</tr>
<tr>
<td>169</td>
<td>py</td>
<td>175.4632</td>
</tr>
<tr>
<td>170</td>
<td>py</td>
<td>176.7332</td>
</tr>
<tr>
<td>171</td>
<td>py</td>
<td>178.0032</td>
</tr>
<tr>
<td>172</td>
<td>py</td>
<td>179.2732</td>
</tr>
<tr>
<td>173</td>
<td>py</td>
<td>180.5432</td>
</tr>
<tr>
<td>174</td>
<td>py</td>
<td>181.8132</td>
</tr>
<tr>
<td>175</td>
<td>py</td>
<td>183.0832</td>
</tr>
<tr>
<td>176</td>
<td>py</td>
<td>184.3532</td>
</tr>
<tr>
<td>177</td>
<td>py</td>
<td>185.6232</td>
</tr>
<tr>
<td>178</td>
<td>py</td>
<td>186.8932</td>
</tr>
<tr>
<td>179</td>
<td>py</td>
<td>188.1632</td>
</tr>
<tr>
<td>180</td>
<td>py</td>
<td>190.0</td>
</tr>
<tr>
<td>181</td>
<td>py</td>
<td>191.25</td>
</tr>
<tr>
<td>182</td>
<td>py</td>
<td>192.5</td>
</tr>
<tr>
<td>183</td>
<td>py</td>
<td>193.75</td>
</tr>
<tr>
<td>184</td>
<td>py</td>
<td>195.0</td>
</tr>
<tr>
<td>185</td>
<td>py</td>
<td>196.25</td>
</tr>
<tr>
<td>186</td>
<td>py</td>
<td>197.5</td>
</tr>
<tr>
<td>187</td>
<td>py</td>
<td>198.75</td>
</tr>
<tr>
<td>188</td>
<td>py</td>
<td>200.0</td>
</tr>
<tr>
<td>189</td>
<td>py</td>
<td>201.25</td>
</tr>
<tr>
<td>190</td>
<td>py</td>
<td>202.5</td>
</tr>
<tr>
<td>191</td>
<td>py</td>
<td>203.75</td>
</tr>
<tr>
<td>192</td>
<td>py</td>
<td>205.0</td>
</tr>
<tr>
<td>193</td>
<td>py</td>
<td>206.25</td>
</tr>
<tr>
<td>194</td>
<td>py</td>
<td>207.5</td>
</tr>
<tr>
<td>195</td>
<td>py</td>
<td>208.75</td>
</tr>
<tr>
<td>196</td>
<td>py</td>
<td>210.0</td>
</tr>
<tr>
<td>197</td>
<td>py</td>
<td>211.25</td>
</tr>
<tr>
<td>198</td>
<td>py</td>
<td>212.5</td>
</tr>
<tr>
<td>199</td>
<td>py</td>
<td>213.75</td>
</tr>
<tr>
<td>200</td>
<td>py</td>
<td>215.0</td>
</tr>
<tr>
<td>201</td>
<td>py</td>
<td>216.25</td>
</tr>
<tr>
<td>202</td>
<td>py</td>
<td>217.5</td>
</tr>
<tr>
<td>203</td>
<td>py</td>
<td>218.75</td>
</tr>
<tr>
<td>204</td>
<td>py</td>
<td>220.0</td>
</tr>
<tr>
<td>205</td>
<td>py</td>
<td>221.25</td>
</tr>
<tr>
<td>206</td>
<td>py</td>
<td>222.5</td>
</tr>
<tr>
<td>207</td>
<td>py</td>
<td>223.75</td>
</tr>
<tr>
<td>208</td>
<td>py</td>
<td>225.0</td>
</tr>
<tr>
<td>209</td>
<td>py</td>
<td>226.25</td>
</tr>
<tr>
<td>210</td>
<td>py</td>
<td>227.5</td>
</tr>
<tr>
<td>211</td>
<td>py</td>
<td>228.75</td>
</tr>
<tr>
<td>212</td>
<td>py</td>
<td>230.0</td>
</tr>
<tr>
<td>213</td>
<td>py</td>
<td>231.25</td>
</tr>
<tr>
<td>214</td>
<td>py</td>
<td>232.5</td>
</tr>
<tr>
<td>215</td>
<td>py</td>
<td>233.75</td>
</tr>
<tr>
<td>216</td>
<td>py</td>
<td>235.0</td>
</tr>
<tr>
<td>217</td>
<td>py</td>
<td>236.25</td>
</tr>
<tr>
<td>218</td>
<td>py</td>
<td>237.5</td>
</tr>
</tbody>
</table>
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 56.48544
447 1 py 59.02544
448 1 py 61.56544
449 1 py 64.10544
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
459 cy 27.94 $ Same as 432
460 1 py 59.025440
461 1 cy 1.27
c 462 py 719.5225

463 py 699.78
464 py 702.32
465 py 704.86
466 py 707.40
467 py 709.94
468 py 712.48
469 py 715.02
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
500  1 py -50.77206
501  1 py -53.31206
502  1 py -55.85206
503  1 py -58.39206
504  1 py -60.93206
505  py 636.28
506  py 633.74
507  py 631.20
508  1 cy 33.02
509  1 cy 34.29  $ RADIUS OF PIG
510  cy 30.48  $ Outer dia of TIVAR (2ft dia); same as 433
511  ************************** BOTTOM LID ADDITION **************************
512  py 498.5512  $ Vacuum Side of Bottom Lid (3/4" thick)
513  cy 157.48
514  cy 154.94
515  cy 152.40
516  cy 149.86
517  cy 147.32
518  cy 144.78
519  cy 142.24
520  cy 139.70
521  cy 137.16
522  cy 134.62
523  cy 132.08
524  cy 129.54
525  cy 127.00
526  cy 124.46
527  cy 121.92
528  cy 119.38
529  cy 116.84
530  cy 114.30
531  cy 111.76
532  cy 109.22
533  cy 106.68
534  cy 104.14
535  cy 101.60
536  cy 99.06
537  cy 96.52
538  cy 93.98
539  cy 91.44
540  cy 88.90
541  cy 86.36
542  cy 83.82
543  cy 81.28
544  cy 78.74
545  cy 76.20
546  cy 73.66
547  cy 71.12
548  cy 68.58
549  cy 66.04
550  cy 63.50
551  cy 60.96
552  cy 58.42
553  cy 55.88
554  cy 53.34
555  cy 50.80
556  cy 48.26
557  cy 45.72
558  cy 43.18
559  cy 40.64
560  cy 38.10
561  cy 35.56
562  cy 33.02  $ SAME AS 508
563  cy 30.48  $ SAME AS 433
564  cy 27.94  $ SAME AS 432
$ 2$ HOLE THRU COPPER PLATES

9/16" COPPER PLATE ABOVE SHIELD PLATE

ELEVATOR FLOOR 20.25" B/L PIG

THICKNESS OF ELEVATOR (1")

TO "STAGGER" W PLUG

NOTE: SIDE PLATES ON PIG ARE IN CORRECT POSITION
(i.e., ON SIDES WHERE YOKE ATTACHES)

OUTER PLANE OF SIDE PLATES ON PIG

WIDTH OF SIDE PLATES 7.75"

$ " " " " " $

OUTER PLANE OF SIDE PLATES ON PIG

SURFACE 692 TRANSFORMED BELOW
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 -137.13206
717  1 py -139.67206
718  1 py -142.21206
719  1 py -144.75206
720  1 py -147.29206
721  1 py -149.83206
722  1 py -152.37206
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
735  1 py -151.10206
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
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 " "
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
768  1 py -154.91206 $ SURFACES FOR 4 FOOT
769  1 py -157.45206 $ POLY COLLIMATOR
770  1 py -159.99206 $ (TURNS OUT, 4 FEET IS
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
c 781   1 cy 38.1
c 782   1 cy 38.735
c 783   py 819.82456001
784   py 822.36459999 $ 822.2
785   py 823.634567
c 786    cy 55.88
c 787    px 55.88
c 788    pz 55.88
c 789    px -55.88
c 790    pz -55.88
c 791    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
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
795   BOX -41.91 801 -54.1  83.82 0 0  0 11.43 0  0 0 1.27001
796   BOX -41.91 811.59 -54.101  83.8201 0 0  0 1.27 0  0 0 3.29
797   BOX -41.91 801 52.9  83.81999 0 0  0 11.43 0  0 0 1.27
798   BOX -41.91 811.5 50.87  83.820001 0 0  0 1.27 0  0 0 3.3
799   BOX -19.85 819.82456 -19.587517 39.7002 0 0  0 2.54 0  0 0 39.7002
799   BOX -10.16 809.66456 -39.37 20.32 0 0  0 10.16 0  0 0 78.74
800   BOX -9.525 810.29956 -39.37 19.05 0 0  0 8.89 0  0 0 78.74
801    BOTTOM OF YOKE: 4" x 8" x 1/4"
802    **** 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 -23.9985
910   py -26.6385
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
isotropic fusion point source at (0,-30.48,0)
mode n p
sdef par=1 erg=d2 pos=0 -30.48 0 $ dir=d1 vec=0 1 0
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;
2 is DD Source, 1 is DT Source
Air at Sea Level (TO ILLUSTRATE SOURCE LOCATION)
m11 7014.50c -0.765 &
m12 8016.50c -0.235
tungsten
m2 74000.55c 1
scintillator [BC-418 OR BC-422Q]
m6 1001.60c 1.1 6000.60c 1 $ NOTE: CHANGED FROM .50c TO .60c
Copper Plates
m4 29000.50c 1
Copper Plates
m4 29000.50c 1
Lead
m5 82000.50c 1
Aluminum G-15 (MCNP5 Manual)
m7 13027.50c 1
High Molecular Weight Polyethylene
m8 26000.55c -0.9796 6000.50c -0.0204
Steel (FOR BOTTOM LID; 97.96% Fe, 2.04% C)
m8 26000.55c -0.9796 6000.50c -0.0204
Polyethylene Collimator on top of Pig (C2H4)
m9 1001.50c 4 6000.50c 2
Lucite Light Guides (Density = 1.19 g/cc)
m10 1001.60c -0.080538 6000.60c -0.599848 8016.60c -0.319614
Stainless Steel (67.5% Fe, 19% Cr, 10% Ni, 2% Mn, 1% Si, 0.5% Cu) G-13

*** CELL IMPORTANCES: ***

**W** 1 1943r 0

**W** 1 1943r 0

*** **** CELL TRANSFORMATION CARD ********************
( FOR HOLE THRU POLY & PIG -- 3.0 DEGREE TILT )
PIG IS SET AT ACTUAL FIELDING POSITION, 3 DEG OFF AXIS

ORIGIN OF x', y', z' COORD SYSTEM:
39.437617 722.03456 0

HOWEVER, PUTTING PIG BACK ON AXIS,
SO NO TRANSFORMATION

x - x': 360.0 DEGREES
y - x': 90 DEGREES
z - x': 90 DEGREES

x - y': 90 DEGREES
y - y': 90 DEGREES
z - y': 90 DEGREES

x - z': 90 DEGREES
y - z': 90 DEGREES
z - z': 0 DEGREES

*TR1 39.437617 722.03456 0 357.0 267.0 90 87.0 357.0 90 90 90 0 1

**** CELL TRANSFORMATION CARDS (FOR PART OF CHASSIS) ****

*TR2 -2.472383 822.36456 -41.91 0 90 90 90 45 45 90 135 45 1

*TR3 -2.472383 822.36456 41.91 0 90 90 90 45 45 90 45 45 1

*TR4 0 0 0 45 90 135 90 0 90 135 90 225

WEIGHT WINDOW GENERATOR CARD

WWG 5 0 $ Ask WW Generator to find weights
5 - Tally ; 1 - Source Cell; 0 - Use mesh-based
 generator (MESH Card)

MESH-BASED WEIGHT WINDOW GENERATOR:

NOTE: ORIGIN AT LOWER LEFT; IMESH, JMESH, KMESH ARE COORDINATES
OF UPPER RIGHT, COVERING ALL GEOMETRY.

mesh geom rec origin -163 -62.5 -163 ref 0 -62.4 0

**** NOTE: FOR MCNP4C, 2 COARSE MESHES PER DIRECTION ARE REQ'D!! ****

imesh 0.0 163 iints 25 25 $ 2 COARSE MESHES B/W -163 TO 0.0
 AND 0.0 TO +163

jmesh 395.9 853 jints 25 25 $ 2 COARSE MESHES B/W -62.5 TO 395.9
 AND 395.9 TO 853 <= TO ELEVATOR!!

kmesh 0.0 163 kints 25 25 $ 2 COARSE MESHES B/W -163 TO 0.0
 AND 0.0 TO 163
*************** WEIGHT WINDOW PARAMETER CARD ***************

WWP:n 4j -1 $ <= -1 TO GET WT WINDOW LOWER BOUNDS FROM EXTERNAL WWINP FILE

********** DXTRAN CARD **********

***** TOP nTOF *****

NOTE: DIFFERENT COORDS x,y,z SINCE TRANSFORMING PIG TO 3 DEGREE TILT

x          y   z  RI1 RI2 DWC1  DWC2 DPWT
|          |   |  |   |    |     |    |
DXT:n 42.464451 779.79 0 4.6 4.6 1000.0 0.0 0.001

1000.0 = UPPER WT CUTOFF IN SPHERE (DWC1)
0.0  = LOWER WT CUTOFF IN SPHERE (DWC2)
0.001  = MINIMUM PHOTON WT (DPWT)

********** FORCED COLLISIONS CARD **********

FOR CELL 276 (SCINTILLATOR)

w/ xi = -1, FORCED COLLISION ONLY APPLIES TO PARTICLES ENTERING THE CELL

xi = -1

FCL:n 0 204R -1 0 1738R

******** VOLUME CARD FOR SCINTILLATOR CELL (276) ********

VOL 205J 115.83333 1739J

********** PHOTON PRODUCTION BIAS CARD (PIKMT) **********

(LOOKING AT NEUTRON-INDUCED PHOTON PRODUCTION)

NOTE: ALL PHOTON PRODUCTION DONE WITH NORMAL SAMPLING TECHNIQUES)

PIKMT ZAID(1) ipik(1) mt(1) pmt(1)

ZAID FOR H

ipik > 0, photon production is biased for ZAID(1);

[if ipik = 0, photons produced from ZAID(1) are done with normal sampling techniques]

MT = reaction identifier for the photon-production to be sampled (in this case, 102 = n,gamma; (only used if ipik>0)

Controls the frequency with which the specified MT reactions are sampled (only used if ipik>0)

PIKMT 1001 0 $ 102 1

6000 0 $ <= photons produced from Carbon

13027 0 $ <= photons produced from Aluminum
26000 0 $ <= photons produced from Iron
74000 0 $ <= photons produced from Tungsten
82000 0 $ <= photons produced from Lead

PHOTON WEIGHT CARD (PWT) (COMMENTED OUT)

[CONTROLS THE NUMBER AND WEIGHT OF NEUTRON-INDUCED PHOTONS
PRODUCED AT NEUTRON COLLISIONS. ONLY PROMPT PHOTONS ARE
PRODUCED FROM NEUTRON COLLISIONS. DELAYED GAMMAS ARE
NEGLIGENCE BY MCNP.]

PWT W1 W2 W3 ... WI (DEFAULT VALUE: Wi = -1)
PWT -1 1943r 0

TALLY n FLUX @ DETECTOR AND PIG:
F4 @ Detector:
F4:n 276

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 51.5 55.0 60.0 65.0 70.0 75.0 80.0 85.0

POINT DETECTOR RIGHT IN THE MIDDLE OF THE SCINTILLATOR
F5:n 42,464451 779.79 0 4.6

$ 43.47 = x COORD OF PT DETECTOR
(SAME AS DXTRAN SPHERE)
$ 779.79 = y COORD OF PT DETECTOR
(SAME AS DXTRAN SPHERE)
$ 0 = z COORD OF PT DETECTOR
$ R0 = RADIUS OF SPHERE OF EXCLUSION
(INCLUDES SCINTILLATOR AND ALUMINUM SHELL;
SAME AS DXTRAN SPHERE ABOVE)

F6 ENERGY DEPOSITED IN SCINTILLATOR
F6:n 276

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
nps 1.0E+07 $ 10 Million Particles
c
PRINT $ Print All Tables
c
cut:n 85 0 $ Time cutoff --
c Lower energy cutoff is zero MeV
c
******************************************************************************

PHYS:N J 20.0
c
PHYS:P 0 1 1
c
CUT:P 85 J 0 $ CUT:P CARD JUST LIKE CUT:N CARD ABOVE (85 SHAKES)
c
IDUM 0 0 0 0 J 1 1 276
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
RDUM 0.0 0.0 $ ENERGY DEP BY n'S MUST EXCEED 0.0 eV TO BE PRINTED
c                    " " " p's " " 0.0 " " "
c
FILES 21 DUMN1
c
******************************************************************************
c MESH TALLY $ NO MESH TALLY TO SAVE TIME
tmesh
 rmesh1:n flux
coral -162.56 100i 162.56
corb1 -30.48 100i 739.84
corc1 -162.56 162.56
endmd
c
NOTE: REMOVING TRAKS AND POPUL MESH TALLIES
c TO SHORTEN RUN TIME
 rmesh11:n traks
coral11 -162.56 100i 162.56
corb11 -30.48 100i 739.84
corc11 -162.56 162.56
rmesh21:n popul
cora21 -162.56 100i 162.56
corb21 -30.48 100i 739.84
corc21 -162.56 162.56
endmd
% Loads and analyzes MCNP-POLIMI output file

% nTOF -- THIS READS THE .DAT INPUT FILE
% AND CALCULATES THE LIGHT OUTPUT VS TIME IN SHAKES
%
% 15 columns of ascii output file have the following information:
%  # of Start Event, Part #, Part Type, Reaction type (Ntyn), ZAID
% collision nucleus, detector cell #,
% energy rel (MeV), time (shakes), x, y, z, wgt, generation #, #
% scatterings, mtp or code, energy of
% particle prior to present collision

% note: in the variable names p=photon; n=neutron
%
% **************** GLOBAL VARIABLES
*********************************************
%
global lonc ncal pcal data tmax nTOF coll maxrow
%
*************************************************** ********************
******

% ****************************** INPUT BLOCK
******************************
%
% ****************** LIGHT OUTPUT OPTIONS ********* **************
% Light Output for n on hydrogen
ncal=[0.0364 0.125 0];
% Light Output for n on Carbon
lonc=0.02;
% Light Output for Gamma on Electron
lop=1;
% Parameters for Line in Calib: photons
pcal=[lop 0];

% ****************************** INPUT BLOCK
******************************

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

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(filen);  % 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(' ************************************************* ')

% ***************************** 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)*lonc;
            % light output = energy deposited * light
        else
            disp(['! error, the struck nucleus is unknown ',
                 int2str(data(j,5))])
        end
    end
end

137
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


% 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

disp(' ')
disp(' Assigning Time to Middle of Bin')
% ASSIGNING TIME TO MIDDLE OF BIN:
    for j = 1:maxrow
        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(filen=='.');  % If '.' in filename, ind1=# of characters up to '.'
%  if ind1
%    root=filen(1:ind1-1);  % root=filename w/o '.'
%  else
%    root=filen;  % 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
% 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 /\(\sqrt{8 \times \log(2)}\);
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 Guassian with zeros

SumGaussian = zeros(1,1);

% k=0;
1 = 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);
     end
   end

% disp(' ');
% disp([' NewGaussian(',int2str(n) ',',' int2str(m),') = '
       ',num2str(NewGaussian(n,m))]);
% disp(' ');}
NewGaussianFinal = zeros(nrow, maxcol);
p = width;

% **************** SHIFTING DATA IN ROWS ********** ****
for i = 2:nrow;
    for j = p:-1:1;
        NewGaussianFinal(i, i-1+j) = 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
end

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

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;
```matlab
    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

    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
')]);
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
')]);
    % disp(' ')
    Constant = Constant * 1.0E04;
    % disp([' Constant = ', num2str(Constant,'%12.7f
')]);
    % disp(' ')
    Constant = round(Constant);
    % disp([' Constant = ', num2str(Constant,'%12.7f
')]);
    % disp(' ')
    Constant = Constant/1.0E04;
    % disp([' Constant = ', num2str(Constant,'%12.7f
')]);
end
for m = 1:width;

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

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
%M 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) = 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]);

if writefile==1
    % indl=find(fileout=='.'); % If '.' in filename, indl=# of characters
    % up to '.'
    if indl
        root=fileout(1:indl-1); % root=filename w/o '.'
    else
        root=fileout;
    end
    dlmwrite(root, timelight); % Writes matrix timelight into ASCII format
end
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 Timel, 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 (*,') 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
10 FORMAT(F7.4, 1x, F11.6) ! FILE OF ANY LENGTH AND STORES THE
    ! 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, Timel
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
    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)

! *************************
!C WRITE RESPONSE FUNCTION TO FILE

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)
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)
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 twofft(data1, data2, fft1, fft2, n)
INTEGER n
REAL data1(n), data2(n)
COMPLEX fft1(n), fft2(n)
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
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

![Idaho Accelerator Center (IAC) Layout](image)

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.

![Graph showing experimental time response with FWHM ~ 7.5 ns](image)

**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 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.

![Graph showing neutron signal with second scattering peak at 460 ns](image)

**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 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 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. 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.
REFERENCES


Metal,” Nuclear Mathematical and Computational Sciences: A Century in Review, A
Century Anew, Gatlinburg, Tennessee, April 6 – 11, 2003, on CD-ROM, American Nuclear

of Nuclear Engineering Department, Politecnico di Milano, November 2002.


electron.

1964.


Efficiencies in Plastic Scintillator, “Ohio State University Preprint COO-1545-92,
Columbus, OH, USA, 1971.


[23] For more information, see “Savitzky-Golay smoothing filter” at

http://en.wikipedia.org

[24] For a summary of IAC facilities and contact information, see http://www.iac.isu.edu


    Sausalito, CA, 1997.

[27] For a summary TIVAR 1000 properties and contact information, see

http://www.quadrantplastics.com

[28] National Security Technologies, North Las Vegas Operations, North Las Vegas,
    Nevada.

[29] Personal Correspondence with Dr. Carlos Ruiz, PMTS, of Sandia National
    Laboratories.

[30] 1 shake = 10^{-08} sec = 10 ns.


