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UPPER LIMITS ON NEUTRON BURSTS EMITTED FROM Ti IN PRESSURIZED D_2 GAS CELLS *

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ABSTRACT

In a search for bursts of neutrons from Ti in pressurized D_2 gas cells ("dry cells"), no statistically significant deviations from the background were observed for events where five or more neutrons are detected over a ten day experiment, including 103 hours of counting with cells on, and 28 hours counting of various backgrounds. Up to four cells were used including some 60 grams (each) of 662-Ti fillings in a pressurized cylinder with 40-60 atmosphere of D_2 gas. Other Ti samples were used too. The samples were cooled to liquid nitrogen temperature and placed in front of the neutron detector while warming up to room temperature. Seven cooling cycles (of some 9 hours each) were used, for each sample. The neutron detector system included 12 liquid scintillator neutron detectors, arranged in a close packed geometry, with six detectors in the upper hemisphere and six in the lower hemisphere. A central detector placed 2 cm from the cells (ϵ=10±3%) was used, in each hemisphere, as a scatterer for a time of flight coincidence measurement, yielding the total coincidence efficiency of ϵ=2±1%. The system was also used in singles mode to allow for counting with large efficiency (ϵ=28±5%). A neutron event is characterized by measuring its pulse heights, pulse shapes, and in some cases its time of flight. Special attention was given to reducing the background by using massive shielding, cosmic ray veto counters and geometrical arrangement that allowed to distinguish between a background event and expected data events. The so obtained background rate are 100

cph in the "singles mode" and in the upper hemisphere 0.4 cph in the "coincidence mode". Two events including 5 detected neutrons were observed in the background runs (28 hours) and two events including 5 and 6 detected neutrons were measured with the cells on (103 hours). All four events were vetoed by the cosmic ray veto counter and they appear consistent with background events. The 3σ upper limit that we deduce on the emission of bursts in our data corresponds to a neutron source smaller than 27 neutrons over 103 hours from some 200 grams of Ti. We are currently continuing our data analysis in search for random emission and a detailed study of background effects that may reveal the origin of conflicting results reported on neutron emission from "cold fusion".

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DISCLAIMER

In a collaboration between Yale University, Brigham Young University and Brookhaven National Laboratory, data was taken at the Wright Laboratory at Yale, over the period spanning August 20-29, 1989. So far the data was analyzed independently at Yale University and Brookhaven National Laboratory, with an analysis at Brigham Young University in progress. In this report we release a preliminary set of our data from the above analyses, for the use of the DOE/ERAB committee. While this report is complete, we emphasize that the analysis of data is still in progress concerning other aspects of the data. The final results will be covered in our forthcoming article to be submitted for publication in the near future.

I. INTRODUCTION

Recent evidence for "cold fusion" [1] was reported by Menlove et al. in a Los Alamos - Brigham Young University experiment [2], where bursts of neutrons were reported from pressurized D_2 cells containing Ti fillings ("dry cells"). The cells were cooled to liquid nitrogen temperature and while warming up were placed in front of the Los Alamos neutron detection system including 12 ^{3}He counters with total efficiency of ϵ=30%. The bursts were observed around 30-40 minuets through the warm up cycle at a cell temperature of about -30°C. We have searched for bursts of neutrons using three to four such "dry cells" of essentially identical characteristics, and report here on results which do not show statistically significant deviations from the background, for high fold events. The detector system that we used can be operated in various modes and here we report on data using the high efficiency (ϵ=28±5%) mode. Several other tests of "dry cells" fabricated in Brookhaven National Laboratory were also used in this search, with similar results obtained.

II. EXPERIMENTAL ARRANGEMENT

The "dry cells" used in this experiment included some 60 grams (each) of 662-Ti fillings, contained in a 40-60 atmospheres of D_2 gas. The cylinders were cooled to liquid nitrogen temperature and than allowed to warm up to room temperature. In Table I we list the experiments performed, and the cylinders used are specified in Table II, including details of the Ti material. In addition three cylinders prepared in Brookahven National Laboratory were used and the details of these cells will be presented in our forthcoming publication. Each set of cylinders was studied over 7 warm up cycles of some 9 hours each, as listed in Table I.

The experimental setup is very similar to the one used in a previous Yale-Brookhaven collaboration on "cold fusion". We refer the reader to Ref. 3 for details of the neutron detectors and veto counters as well the operation of the system and the various cuts that can be placed on the pulse shape, pulse height and time of flight parameters in the analysis of the data. In Fig. 1 we show the experimental arrangement drawn to scale, including two central detectors, U0 and D0, placed 2 cm from the cells and used as scatterers and ten ring detectors, as described in Ref. 3. We list here the various improvements in the system as compared to that used in Ref. 3. (1) Twelve neutron detectors were used in this experiment, instead of the six used in Ref. 3. The detectors were arranged in two hemispheres allowing for measurement of up-down asymmetry. In this way one may discern downward moving (background) neutrons, from neutrons originating in the cells which move upward in the upper hemisphere. (2) Three veto counters were used to span a larger solid angle as shown in Fig. 1. (3) The shielding of the setup was improved with the use of some 20 tons of concrete blocks containing iron (of dimension 45x45x60 cm, each).

The efficiencies of our neutron detectors were measured using a calibrated ^{252}Cf source, placed in the center of the detector system, as well as on the edge of the pentagonal central detectors. The efficiency of the central detectors was found to be ϵ(U0) = ϵ(D0)=10±3% and each detector in the outer rings, U1-U5 or D1-D5, was measured to have an efficiency of 0.8%. Thus when all detectors are counted without requiring a time of flight coincidences ("singles mode"), a total efficiency of 28±5% is obtained. We emphasize that the efficiency of the central detectors is a factor of 12 larger than that of the ring detectors and for neutrons originating in the cells there is a very small probability that a ring counter will fire without the corresponding central detector. For background events, the efficiency of all detectors is essentially the same allowing a situation where the ring counters fire but not the appropriate central detector. In addition the efficiency for a neutron double hit in a ring detector is 0.006% and for a source including only 20 neutrons it is 0.2%. It is then very unlikely that in the data discussed below double hits occurred in any ring detector. Thus pulse height information from the ring detectors is very crucial for removing higher energy background neutrons. The time of flight coincidence efficiency of each pair of detectors, U0i and D0i, was measured to be 0.2%, yielding a total coincidence efficiency of 2±1%, in the coincidence mode. The efficiency for vetoing cosmic ray related events was measured to be of the order of 65%. In addition we estimated the efficiency for detecting 2.45 MeV neutrons in the veto counters to be 0.6%. Thus for a neutron source including 20 neutrons it is of the order 12% and it is very unlikely that in any of the data discussed below the events were self vetoed.

We have measured for each detector its pulse shape, to facilitate neutron to gamma discrimination, its pulse height, for discrimination against background events where the energy deposited may be larger than 2.45 MeV expected from fusion events, and the time of flight between the scatterer (the central detector) and a ring detector. This allowed for studying the time ordering of events. While neutrons originating in the cells are moving upward in the upper hemisphere (i.e. central detector U0 fires before a ring detector U1-U5), the background events could be moving downward (i.e. with negative time of flight, see below). We however emphasize that it is possible in a burst including large number of neutrons spread in time, for one neutron to be detected in the central detector and a different neutron to be detected in a ring detector, in a time order that mimics a background neutron moving downward. Hence the time ordering of events have to be considered with care and may not be useful in all cases. The data was written onto magnetic tapes event by event (including up to some 50 parameters) for analysis using various cuts as discussed in Ref. 3. An event was accepted only when a signal was registered in one of the two central detectors U0 or D0. A gate 20 μsec wide, was used to allow for accepting all data falling within ±10 μsec with respect to the trigger, i.e. before or after one of the two central detectors fired. Bursts of neutrons spread over more than 20 μsec would not be detected by our system. The detectors were calibrated using standard radioactive sources. The time of flight range of the TACs used was 10 μsec, with 8K dispersion allowing for the study of bursts spanning 10 μsec with an accuracy of 1.25 nsec. Time of flight for neutrons is measured starting from a central detector, hence in the case that a ring detector fired before its central detector the time of flight is negative. The time resolution of the system was measured for γ-γ' events to be 2.5 nsec, as discussed in Ref. 3. The background rate in our experiment is 2 cph in the "coincidence mode" (with

ϵ=2±1%) and in the "singles mode" the background is 100 cph (with ϵ=28±5%).

III. EXPERIMENTAL RESULTS

In this interim report we only present the analysis of our data using the system in "singles mode", where the computer is triggered by one of the central detectors and all other detectors are inspected. In Fig. 2 we show a typical pulse shape gate on neutrons in detector U1. We have chosen a very broad gate on the pulse shape data (in one dimension), so as to make sure that no neutrons are excluded, but in the same time we include background gammas that fall within the broad gate. A histogram of number of detector fired (event fold) was constructed, as shown in Fig. 3, using such gates on the neutron pulse shape, as shown in Fig. 2. Only four events were observed to have high folds of five or six. Two were observed in two separate background runs (spanning 28 hours), in Runs 40 and 51, and two were observed in data runs (spanning 103 hours), in Runs 45 and 61. All 4 high folds events were vetoed by the cosmic ray veto counter. In Fig. 4 we show the time distribution of these high fold events. Note that the time calibration is 0.9 min per channel, and t=0 is a few minuets into the warmup cycle, after the cylinders are removed from the liquid nitrogen bath. The measured cylinder's temperature are shown as a function of time in Fig. 5. The most probable neutron multiplicity (M_n) can be calculated from an event of fold (K) using the efficiency for detecting an event of fold K given by:

$$\epsilon(K) = M_n \times \epsilon(12) * (M_n - 1) * \epsilon(11) * \ldots * (M_n - K) * \epsilon(12-K)$$

For neutron source of multiplicity 125 we obtain 100% efficiency for detecting a neutron in each detector (fold=12), and for multiplicity of 20 we have 100% efficiency of detecting 5 neutrons. Hence a 5 (6) fold event most probably corresponds to a source with neutron multiplicity of M_n= 20 (24).

The list of all observed event parameters is given in Table III. Only in one event (Run 45) both U0 and D0 fired, as would be expected for neutrons originating in the cells. In all events the energy deposited in at least one ring detector is larger than the 2.45 MeV expected from a fusion event. The probability of these events being a hybrid event in which a neutron originating from the cell appears in chance coincidence with a cosmic background event is estimated to be of the order of 10^{-10}, and the probability for a double hit in a ring counter is estimated to be of the order of 0.2%, see below. We thus can conclude based on the energy deposited in the ring detectors that these events are consistent with background events. In fact inspecting the time scale and energy deposited in detectors U5, U1 and U0 we may conclude that the event of Run 45 include one neutron that does triple scattering including one large angle scattering from detector U5 to its neighbor detector U1, and then immediately followed by a small angle scattering into the central detector U0 lying below the ring detectors (thus yielding to negative time of flight). From our data we deduce an upper limit on neutron bursts from our cells to be smaller than 27 neutrons with 98% confidence (3σ).

REFERENCES

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2. H.O. Menlove, M.M. Fowler, E. Garcia, A. Mayer, M.C. Miller, R.R. Ryan, and S.E. Jones, to be published.

3. M. Gai, S.L. Rugari, R.H. France, B.J. Lund, Z.Zhao, A.J. Davenport, H.S. Isaacs, and K.G. Lynn, Nature 340(1989)29.

FIGURE CAPTIONS

Fig. 1: A schematic diagram of the experimental arrangement drawn to scale.

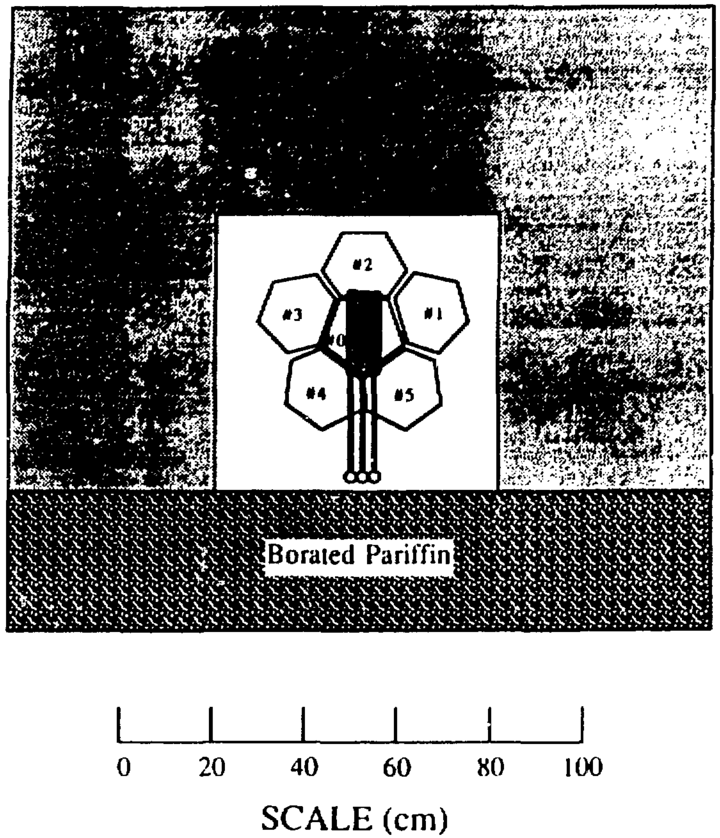
Fig. 2: Typical two dimensional pulse height Vs pulse shape plot for neutron detector U1. In the analysis a one dimensional gate was used as shown in the projection along the pulse shape axis. Events listed in Table III as neutron or gamma events have pulse shapes that fall within 10 channels of the gate's limit (around channel 140).

Fig. 3: Total number of high fold events observed in background runs (28 hours) and data runs (103 hours). The average event rates are proportional to the running time with the same proportionality factor for background and data runs.

Fig. 4: Number of neutrons detected as a function of time into the warm up cycle. The time calibration is 0.9 min per channel, and t=0 is a few minutes after the cylinders were removed from the liquid nitrogen bath. In this surface plot, two adjacent events coincide to yield a continues line.

Fig. 5: Cylinder temperature as a function of time into the warm up cycle.

Top View



SIDE VIEW

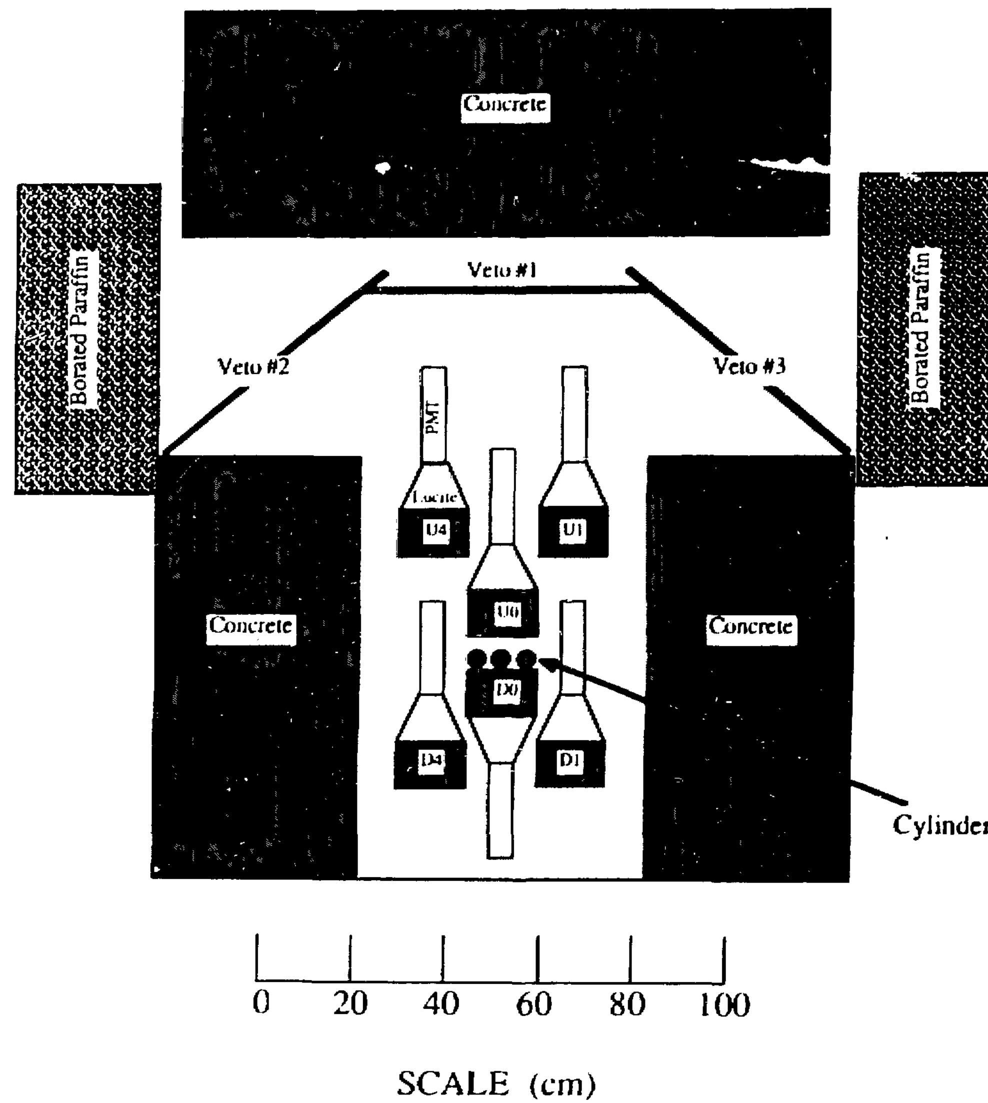
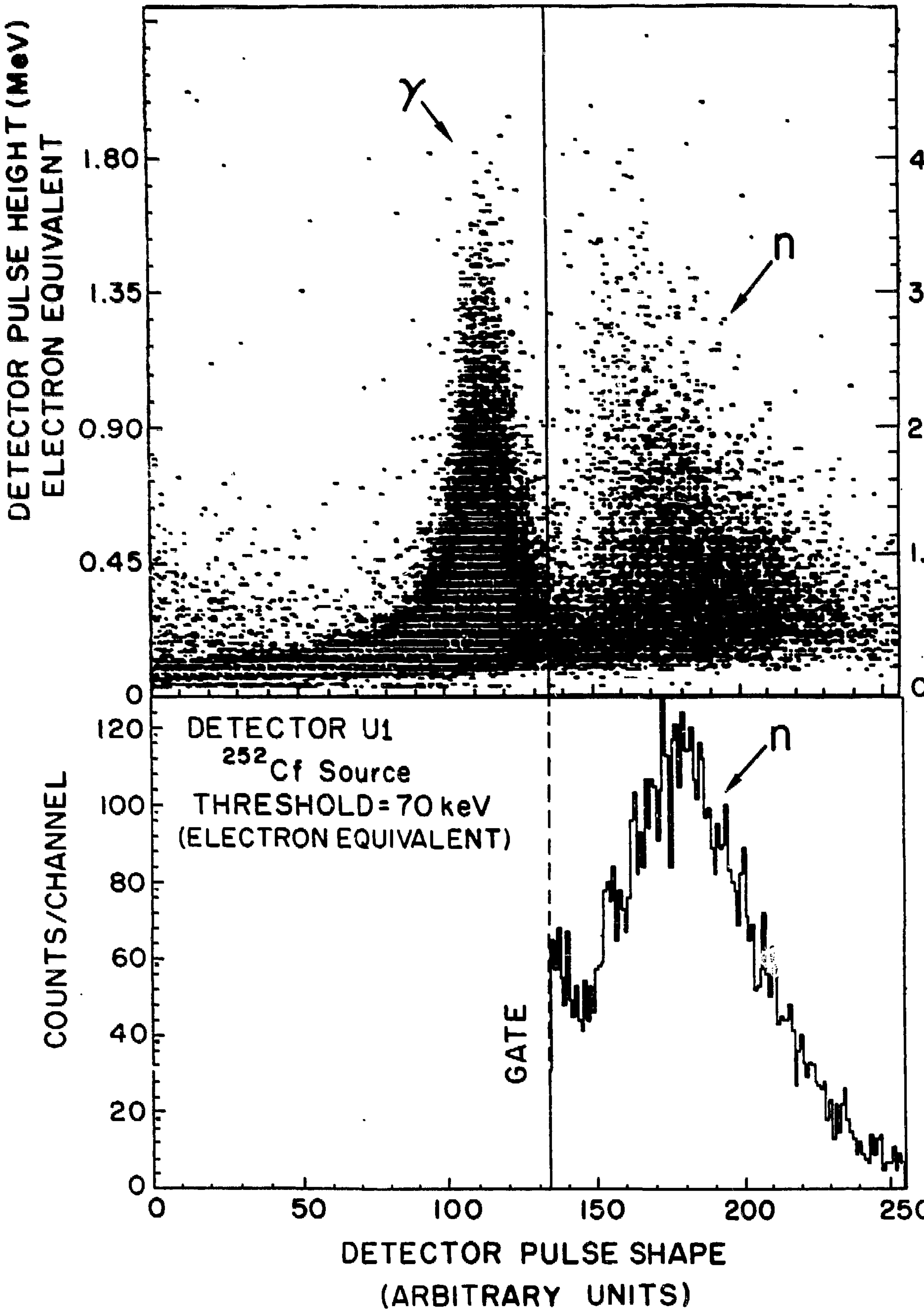
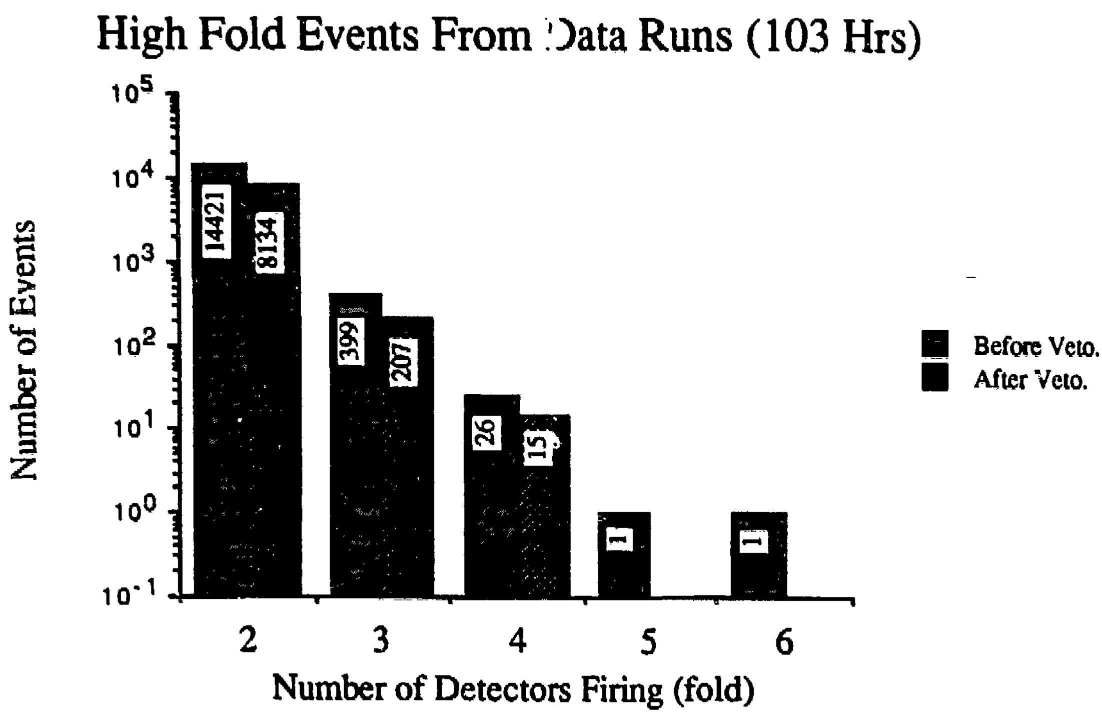


Fig. 1



DETECTOR PULSE HEIGHT (MeV)
ELECTRON EQUIVALENT
1.80
1.35
0.90
0.45
0
γ
n
EQUIVALENT NEUTRON ENERGY (MeV)
4.1
3.6
2.5
1.7
0
COUNTS/CHANNEL
120
100
80
60
40
20
0
DETECTOR U1
^{252}Cf Source
THRESHOLD = 70 keV
(ELECTRON EQUIVALENT)
GATE
n
0
50
100
150
200
250
DETECTOR PULSE SHAPE
(ARBITRARY UNITS)

Fig. 2


High Fold Events From Data Runs (103 Hrs)
Number of Events
Number of Detectors Firing (fold)
Before Veto.
After Veto.
14421
8134
399
207
26
15
1
1

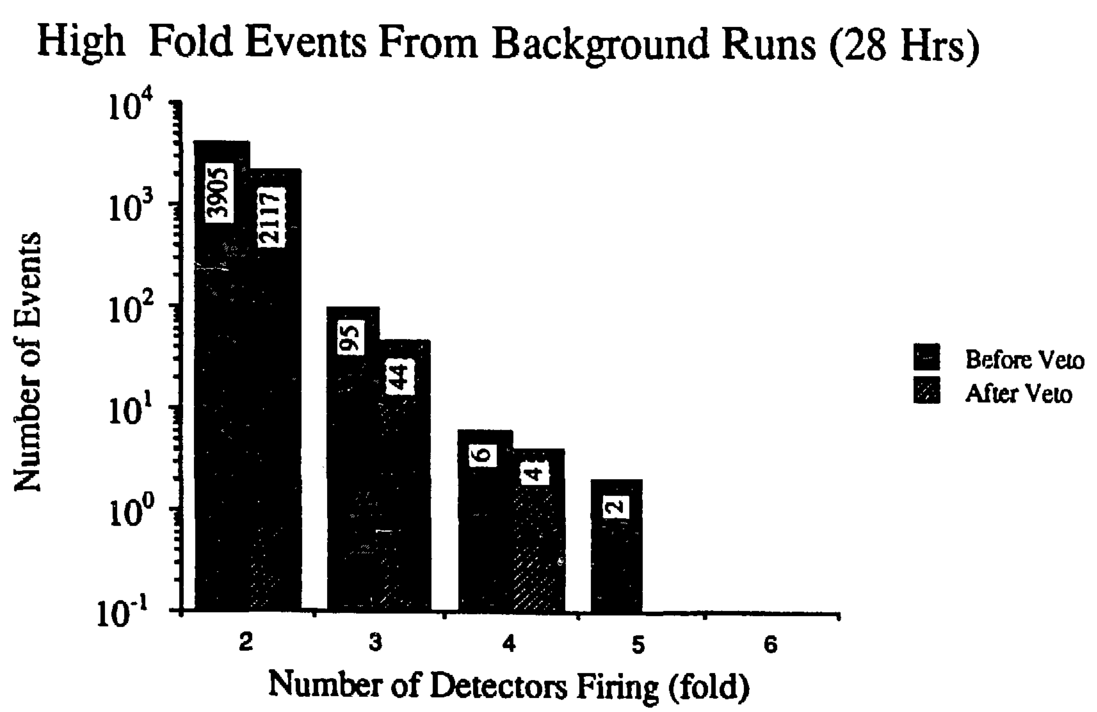
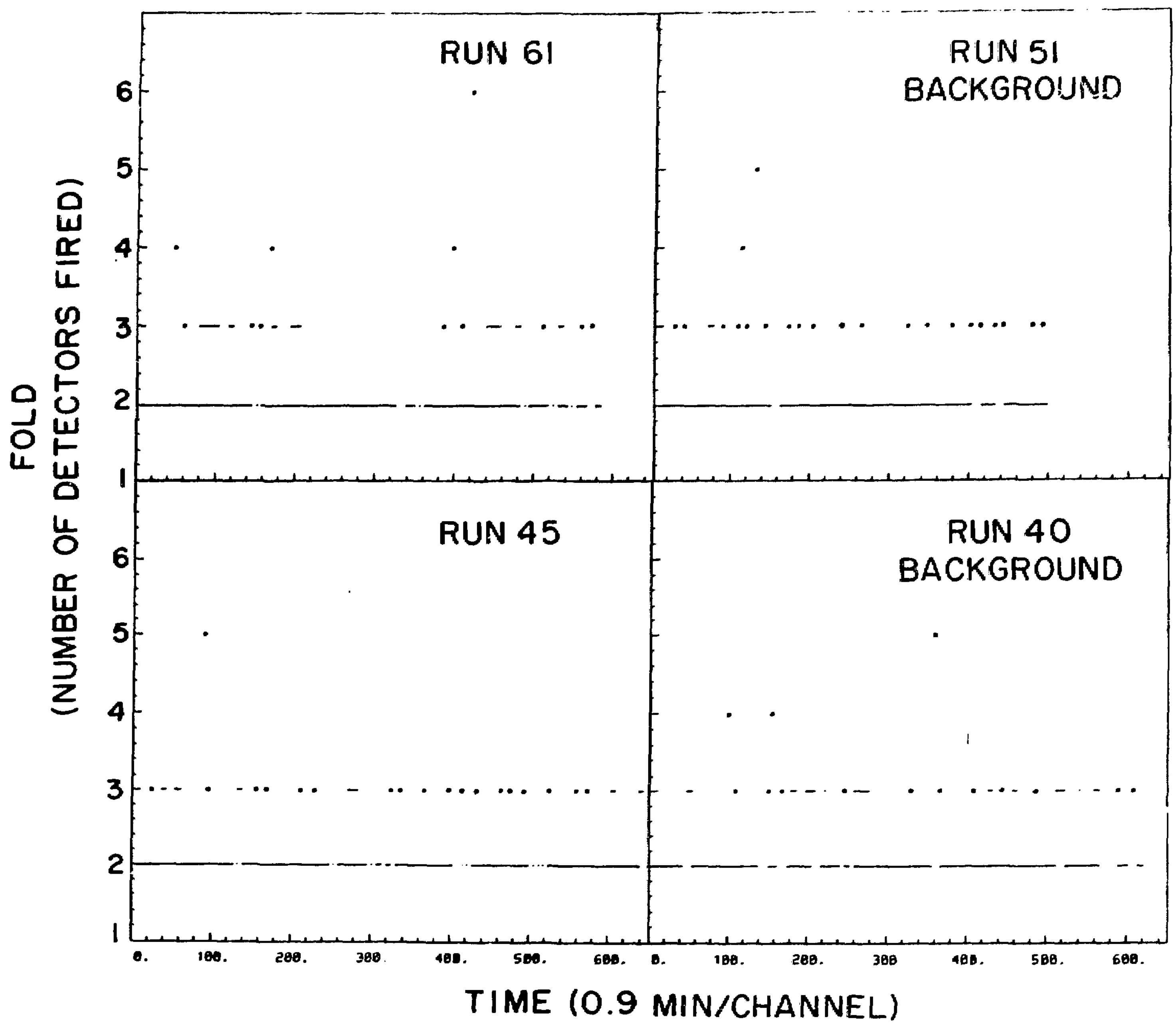

High Fold Events From Background Runs (28 Hrs)
Number of Events
Number of Detectors Firing (fold)
Before Veto
After Veto
3905
2117
95
44
6
4
2

Fig. 3

Fig. 4


RUN 61
RUN 51
BACKGROUND
RUN 45
RUN 40
BACKGROUND
FOLD
(NUMBER OF DETECTORS FIRED)
TIME (0.9 MIN/CHANNEL)

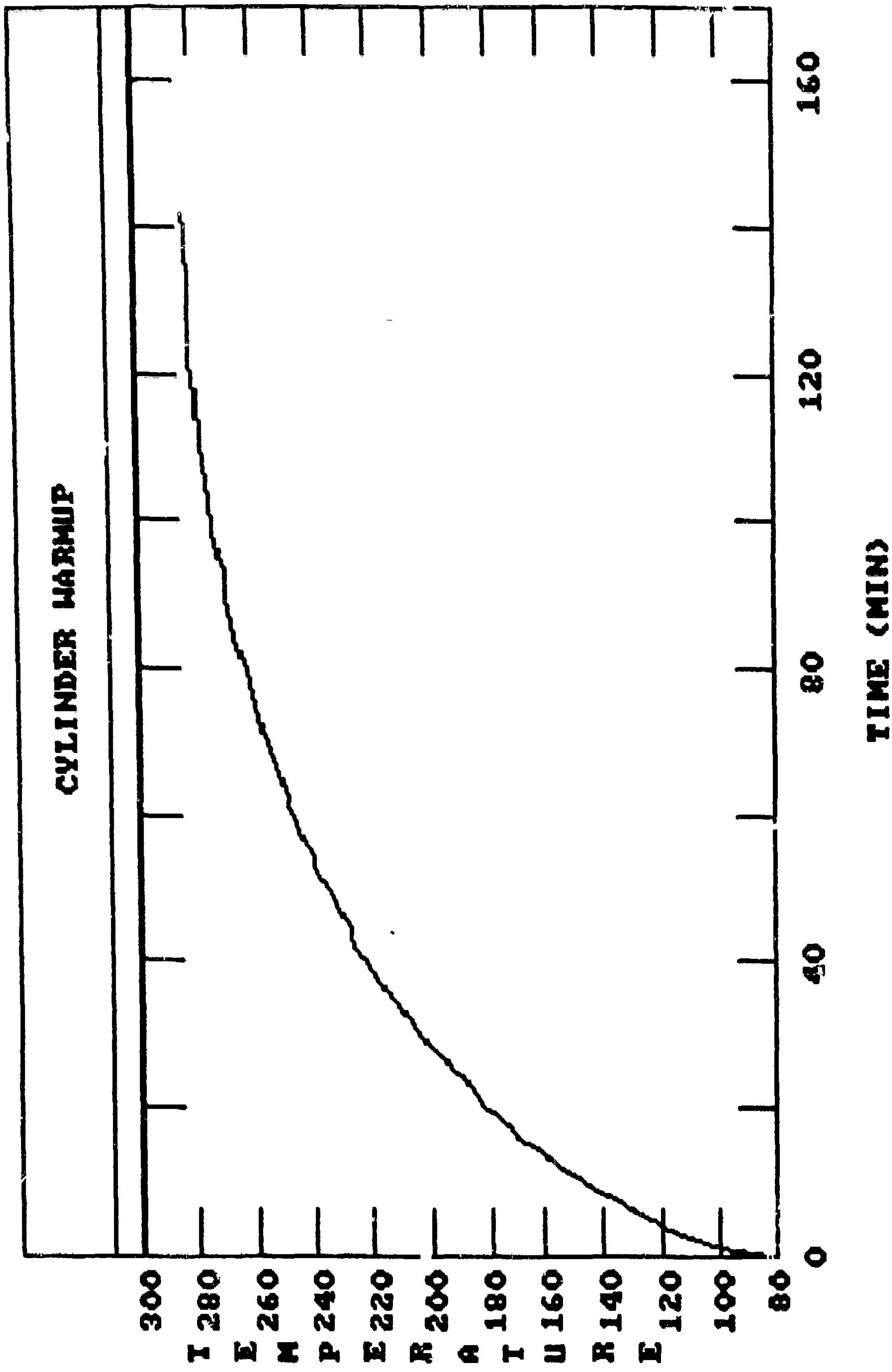

CYLINDER WARMUP
TEMPERATURE
300
280
260
240
220
200
180
160
140
120
100
80
0
40
80
120
160
TIME (MIN)

Fig. 5

Table I: Summary of Runs

Run Number	Type of Run	Cylinder Set	Length of Run	Blocks	Blocks Per Minute*
3	PuBe Neutron Source		0:03		
4	Cs 137 Source		0:01		
5	Co 60 Source		0:01		
11	Cf Source		0:40		
12	Cf Source		<7:48		
14	Cf Source		0:10		
20	Cf Source		0:07		
21	Cf Source		<0:10		
22	Cf Source		0:02	4812	2406
23	Signal Timing Calibration		0:19	1313	69.11
30	Bkgnd	None	0:02	8	4
31	Bkgnd	None	0:20	37	1.9
32	Bkgnd	None	8:16	873	1.76

At this point we adjusted on-line gates, pulse shape discriminators, and the voltages of detectors U0 and D0

33	Co 60 Source				
34	Cf Source		2:16	6732	49.5
35	Bkgnd	1/2 Lead Brick**	1:20	151	1.89
36	Bkgnd	1/2 Lead Brick**	0:23	54	2.35
40	Bkgnd	Set L	8:57	627	1.17
41	Bkgnd	Set L #1	3:33	255	1.20
42	Data Run	Set A #1,2,3	6:15	439	1.17
43	Data Run	Set A	12:30	860	1.15
44	Data Run	Set B	9:22	647	1.15
45	Data Run	Set C	9:46	651	1.11
46	Data Run	Set D	7:23	511	1.15
47	Data Run	Set D	7:53	544	1.15
48	Data Run	Set E	9:47	657	1.12
49	Data Run	Set E	6:26	439	1.14
50	Cf Source		2:57	8329	47.1
51	Bkgnd	Set F	7:30	509	1.13
52	Bkgnd	Set G	4:06	273	1.11
53	Data Run	Set H	4:03	279	1.15
54	Data Run	Set I	4:02	281	1.16
55	Data Run	Set K	4:01	279	1.16
56	Data Run	Set K	4:30	307	1.14
57	Data Run	Set K	4 :00	277	1.15
58	Data Run	Set K	4:25	313	1.18
59	Cf Source		1:00	1797	30.0
60	Bkgnd	Set M	4:01	273	1.13
61	Data Run	Set J	8:44	585	1.12

Notes:

* This number is calculated after first subtracting off the seven header blocks from the blocks column.

** In runs 35 and 36, a 2"x 4"x 3.5" lead brick was placed between detectors U0 and D0.

Table II: Cylinder Sets Used in Experiments

Cylinder Set	Cyl #	Type of Gas	Type of Metal
Set A			
	#1	D_2 @ 780 PSI	60g of thick Ti662 chips from BYU
	#2	D_2 @ 990 PSI	66g of thin Ti662 chips from BYU
	#3	D_2 @ 680 PSI	67g of Ti662 chips from Ormet
	#4	D_2 @ 250 PSI	12g of thin Ti662 chips from BYU and 4g of Ti662 chips from Ormet*
Set B			
	#1	D_2 @ 720 PSI	60g of thick Ti662 chips from BYU
	#2	D_2 @ 980 PSI	66g of thin Ti662 chips from BYU
	#3	D_2 @ 680 PSI	67g of Ti662 chips from Ormet
	#4	D_2 @ unknown PSI	12g of thin Ti662 chips from BYU and 4g of Ti662 chips from Ormet*
Set C			
	#1	D_2 @ 680 PSI	60g of thick Ti662 chips from BYU
	#2	D_2 @ 980 PSI	66g of thin Ti662 chips from BYU
	#3	D_2 @ 680 PSI	67g of Ti662 chips from Ormet
	#4	D_2 @ unknown PSI	12g of thin Ti662 chips from BYU and 4g of Ti662 chips from Ormet*
Set D			
	#1	D_2 @ 660 PSI	60g of thick Ti662 chips from BYU
	#2	D_2 @ 980 PSI	66g of thin Ti662 chips from BYU
	#3	D_2 @ 680 PSI	67g of Ti662 chips from Ormet
	#4	D_2 @ unknown PSI	12g of thin Ti662 chips from BYU and 4g of Ti662 chips from Ormet*
Set E			
	#1	**	
	#2	D_2 @ 980 PSI	66g of thin Ti662 chips from BYU
	#3	D_2 @ 680 PSI	67g of Ti662 chips from Ormet
	#4	D_2 @ unknown PSI	12g of thin Ti662 chips from BYU and 4g of Ti662 chips from Ormet*
Set F			
	#1	H_2 @ 790 PSI	65g of Ti662 chips from BYU
	#2	D_2 @ 790 PSI	No Chips
	#3	Vacuum	65g of Ti662 chips from BYU
Set G			
	#1	H_2 @ 730 PSI	65g of Ti662 chips from BYU
	#2	D_2 @ 780 PSI	No Chips
	#3	Vacuum	65g of Ti662 chips from BYU

Set H			
	#1	D_2 @ 860 PSI	Ti662 chips from BYU
	#2	D_2 @ 860 PSI	Ti662 chips from BYU
	#3	D_2 @ unknown PSI	Thin Ti662 chips from Ormet*
Set I			
	#1	D_2 @ 850 PSI	Ti662 chips from BYU
	#2	D_2 @ 850 PSI	Ti662 chips from BYU
	#3	D_2 @ unknown PSI	Thin Ti662 chips from Ormet*
Set J			
	#1	D_2 @ 860 PSI	Ti662 chips from BYU
	#2	D_2 @ 860 PSI	Ti662 chips from BYU
	#3	D_2 @ unknown PSI	Thin Ti662 chips from Ormet*
Set K			
	#1	D_2 @ 400 PSI	50g of FeTi
	#2	D_2 @ 414 PSI	45.9g of $V(D_2)$
	#3	D_2 @ 415 PSI	20.3014g of Y metal
	#4	D_2 @ 200 PSI	24.98g of $La(D_3)$
Set L			
	#1	H_2 @ 780 PSI	Empty
	#2	Vacuum	Empty
	#3	Vacuum	Empty
	#4	Vacuum	Empty
Set M			
	#1	Vacuum	50g of FeTi

Notes:

* This cylinder was smaller than the others and lacked a pressure gauge.

** This cylinder had a set of used Pd electrodes. It started with D_2 gas at 100 PSI which rapidly fell to a level not measurable with the cylinder's pressure gauge due to the metal adsorbing the gas.

Table III: Summary of High Fold Events

Detector	Energy Deposited (MeV)	Time of Flight (nsec)	Pulse Shape
Five-fold event in background Run 40:			
U0	2.8	0.0	n
U2	0.9	3.7	n
U4	0.9	3.7	n or γ
U5	4.4	-2.4	n or γ
D2	1.5	N/A	n
Five-fold event in background Run 51:			
U3	0.4	N/A	n or γ
U4	2.0	N/A	n
U5	4.4	N/A	n or γ
D0	0.9	0.0	n or γ
D1	1.5	3.7	n or γ
Five-fold event in data Run 45:			
U0	1.8	0.0	n
U1	1.1	-17	n
U3	0.6	3800	n
U5	4.4	-18	n
D0	3.3	N/A	n
Six-fold event in data Run 61:			
U1	0.6	N/A	n
U4	0.4	N/A	n
D0	5.4	N/A	n or γ
D2	1.6	740	n or γ
D4	1.1	1.2	n or γ
D5	4.2	1000	n