Homogeneity study of matrix constituents of a fuel plate through gamma ray transmission

By

Muhammad Usman Rajput Muhammad Akhtar Javaid Iqbal Akhtar

Physics Division Directorate of Science Pakistan Institute of Nuclear Science and Technology Nilore, Islamabad

December, 2008

Table of Contents

S.No.	Contents	Page
	Abstract	ii
1.	Introduction	1
2.	Experimental Set-up of LEU Fuel Gamma Ray Scanning System	2
3.	Gamma Ray Scanning of Fuel Plate	7
4.	Results and Discussion	8
5.	References	9
6.	Appendix- I	11
7.	Appendix- II	13
8.	Appendix- III	15
9.	Appendix- IV	17

Abstract

The R & D work to establish a facility for the study of homogeneity and fuel density i.e., quantity of ²³⁵U in the locally fabricated LEU fuel plates for Pakistan Atomic Research Reactor (PARR-1) has been initiated. This brief report presents the results of our preliminary study in respect of homogeneity of the fuel plate constituents. An elementary experimental facility for nuclear radiation detection with Nal detector has been established. The fuel plate (U₃Si₂-AI) was manually scanned and the transmission of gamma radiation from radioactive ²⁴¹Am source was determined. The study revealed encouraging results about density distribution of the plate constituents. At the same time it has also lead to future improving steps.

Key words: nuclear fuel, gamma ray interaction, gamma ray scanner

1

1. Introduction

i.

Nuclear fuel plays a key role in smooth and successful running of the nuclear reactors. The homogenous distribution of the fissile material in the fuel is an important parameter in the fuel fabrication technology. The inhomogeneous distribution may lead to the formation of high temperature regions in the fuel plates and elements. These regions are called hotspots and may lead to the catastrophic failure of the reactor. The qualification of nuclear fuel therefore becomes very important.

Gamma ray spectroscopic technique serves as a powerful and reliable tool in the qualification of nuclear fuel. The gamma rays of interest to non-destructive analysis fall within the range of 10 keV to 2000 keV depending on the type and geometry of the materials to be scanned. The gamma rays interact with the detectors and the absorbing media (i.e., the fuel plate) by three major processes [1-4], namely, the photoelectric effect, Compton scattering and pair production. In the photoelectric effect, the gamma ray loses all of its energy in the single collision with the bound electrons in the absorbing material. The probability of interaction depends very strongly on the gamma ray energy and the atomic number. The Compton scattering results in the partial loss of energy and the gamma ray suffers multiple collisions. The probability in this process is weakly dependent on the energy and the atomic number. In the pair production process, the threshold for the gamma ray energy is 1.02 MeV which is the rest mass of the two generated electron-positron pair which is equal to 2 X m_oC².

All the above mentioned processes contribute to the complex gamma ray spectrum, especially for the multi gamma emitting nuclides. Based on gamma ray interaction and attenuation phenomenon, gamma ray scanners can be designed. The design and development work of the gamma ray scanner for homogeneity measurement is progressing successfully. This report presents our R & D detail and the results of the scan of one of the fuel plates.

1

2. Experimental Set-up of LEU Fuel Gamma Ray Scanning System

In order to develop a gamma ray scanning system, the following facilities were established at PINSTECH.

- Establishment of gamma ray detection/scanning system for fuel plate homogeneity measurements
- Designing and fabrication of tentative partial lead shielding
- Signal processing
- Manual Scanning of fuel plate
- Marking of scan grids on the fuel plate
- Provision of ²⁴¹Am radioactive source (IAEA-standard)
- Fabrication of holder for radioactive source

The layout of the designed gamma ray scanner is shown in Fig.1 (a). The detection system comprising of NaI(TI) detector, a photomultiplier tube and pre-amp base along with signal cables is inside the lead brick surroundings. The fuel plate is shown in the scanning position in between the detection system and the ²⁴¹Am radionuclide source. The radionuclide is also placed inside the lead shielding in order to avoid the radiation hazard to the personnel during manually scanning the fuel plate. The allied electronic system coupled with the gamma ray detection system is shown in Fig.1 (b). The block diagram of the detection system is shown in Fig. 2.



(a)







Fig.2 : Block diagram of the gamma ray Scanning system

In order to mark the position for measurements and to keep the reproducible geometry conditions, a graphic sheet was attached on one side of the fuel plate. It was numbered (named as segments) vertically and horizontally. The following lines define the segments and measuring positions. The read convention is explained as under:-

Position (2, 12) defines segment #2 which is 2 cm vertical plate position and 12 cm horizontal position from the referenced corner of the fuel plate. In the graphical representation of the data in this report "comma" of position as 2, 12 has been omitted. This position will be taken as 212 for plotting convenience.

Segm	ent	Measuring positions						
Segment	# 2:	(2, 12), (2, 14), (2, 16), (2, 18), (2, 20), (2, 22), (2, 24), (2, 26), (2, 28), (2, 30), (2, 32), (2, 34)						
Segment	# 4:	(4, 12), (4, 14), (4, 16), (4, 18), (4, 20), (4, 22), (4, 24), (4, 26), (4, 28), (4, 30), (4, 32), (4, 34)						

Segment #6: (6, 12), (6, 14), (6, 16), (6, 18), (6, 20), (6, 22), (6, 24), (6, 26), (6, 28), (6, 30), (6, 32), (6, 34)

Segment #8: (8, 12), (8, 14), (8, 16), (8, 18), (8, 20), (8, 22), (8, 24), (8, 26), (8, 28), (8, 30), (8, 32), (8, 34)

The fuel plate grid is shown in Fig.3 (a & b). In the Fig.3 (a), face-1 shows the actual shape of the fuel plate where as face-2 in Fig.3 (b) indicates the pasted graphic sheet used for determining the scanned position and for reproducible remeasurements.

The radioactive source of ²⁴¹Am (IAEA point source standard) was mounted on a fabricated source holder (Fig. 4) and fixed in an appropriate position inside the lead shielding of the scanning system. Several wooden blocks were prepared to keep the fuel plate in stable condition. The plate was manually moved vertically and horizontally on the wooden blocks; however, an additional stable condition was provided by hand holding at certain positions.



Fig.3 : (a) Face1- Actual layout of the uranium silicide fuel plate (b) Face 2gridding of the uranium silicide fuel plate.



Fig 4. IAEA radioactive standard source (Am-241) and the locally fabricated source holder.

3. Gamma Ray Scanning of fuel plate

As the plate contained radioactive material, though of small activity, all the radiation safety measures were undertaken, during manual scanning for data collection. The detection system was optimized by incorporating the Oscilloscope in the electronic circuitry and a gamma ray window was set at single channel analyzer. Fuel plate was manually moved longitudinally and vertically and the transmission of 59 keV gamma ray of Am-241 was recorded at the grids marked earlier, by using the counter/timer of the scanning system. The random nature of

radioactivity required several measurements at each position. The following procedure was adopted.

- Six data points were recorded at each position by manual scanning of the fuel plate (compiled in col. 2 to 6 in Appendix – I to IV). About 300 data sets were collected.
- Corresponding backgrounds were accumulated
- Data points were averaged for each position with an estimate of the corresponding uncertainty.
- The results of the data reduction are compiled. The results are also displayed graphically.

4. Results and Discussion

The fuel plate was scanned at each segment i.e., 2, 4, 6 and 8 as defined earlier. The data obtained at each segment is given as Appendix – I, II, III and IV respectively. The results displayed in figures 6 and 7 are highly encouraging as they show the homogeneity of the fuel plate constituents at the corresponding positions. However, the figures 5 and 8 clearly reveal the existence large variations. The higher gamma transmission is noted in Figs. 5 and 8, whereas Figs. 6 and 7 shows a constant trend with reduced transmission indicating the presence of high-density constituents in the center of the fuel plate with homogeneous distribution. The possible causes of large variations noted from Figs. 5 and 8 were scrutinized and the possible reasons were: gamma ray streaming through the plate edges, the poor collimation and systematic errors that occurred as a result of manual scan. However, these errors were minimized in positions 6 and 7 owing to the central geometry of the plate that has masked the complete detector.

This preliminary study indicated the causes of discrepancies and that would lead to the following future improvements.

- 1. Improvement in the collimation system.
- 2. Requirement of ²⁴¹Am radioactive source of high activity.
- 3. Electrically operated system for fine and stable horizontal/vertical movements of the fuel plates coupled with PC based data acquisition.

This work has been carried out using the only one available fuel plate, whereas better assessment requires few more fuel plates. Hence, further fuel plates with homogeneous and heterogeneous matrix material distribution will be required to conduct a comparative study in order to increase the confidence level. Uranium standards with known concentrations of ²³⁵U are also required to see the possibility of ²³⁵U quantification in the fuel plates.

5. References

[1]. G.F. Knoll, Radiation Detection and Measurements- (3rd-Ed.) (John Wiley & Sons, New York, 1999)

[2]. K. Debertin and R.G. Helmer, Gamma- and X-Ray Spectrometry with Semiconductor Detectors. (North-Holland, Amsterdam, 1988)

[3]. S. Glasstone, A.Sesonske, Nuclear Reactor Engineering, (Van Nostrand Reinhold, New York, 1967)

[4]. G. Gilmore, J. Hemingway, Practical Gamma ray Spectrometry, (John Wiley & Sons Ltd, West Sussex, England, 2004)

APPENDICES

.....

Appendix-I

Measured counting da	ta of 241	Am So	ource - F	uel plate :	seament #	2 scan			sponanti
Source counts		1871	1930	1845	1886	1827	1976	1918	1928
		1889	1911	1963	1939	1946	1885	1883	1891
	Ave	erage ((Above c	ounts) :	1905.50	40.93			
In the following lines	s: Col. 2	to 6 (a	ifter "Po	sition" rov	v contains	the data co	unts)		
Position	2,	12						MEAN	STD.DEV.
Source+Plate counts		832	737	826	799	794	786	795.67	34.03
Back Gnd		126	98	130	150	104	119	121.17	18.81
NET COUNTS								674.50	38.88
Position	2,	14							et generation de la construction de Recursta de la construction de la co
source+Plate counts		732	695	689	712	708	683	703.17	17.93
Back Gnd		114	112	122	126	123	146	123.83	12.14
NET COUNTS								579.33	21.65
Position	2	16							
Source+Plate counts		674	626	640	632	670	661	650.50	20.47
Back Gnd		139	120	142	147	138	130	136.00	9.61
NET COUNTS								514.50	22.62
Position	2,	18						$= \{0, 0\} \{ g \in [\mathcal{S}_{1}^{m}] \} \{ g \in [\mathcal{S}_{2}^{m}] \}$	94 - 26 - 26 - 33
Source+Plate counts		644	610	599	601	656	574	614.00	30.57
Back Gnd		133	151	122	146	111	123	131.00	15.32
NET COUNTS								483.00	34.20
Position	2,	20							
Source+Plate counts		581	555	584	609	566	592	581.17	19.05
Back Gnd		121	127	101	99	134	115	116.17	14.03
NET COUNTS								465.00	, 23.66
Position	2,	22							
Source+Plate counts		616	635	584	630	589	639	075/50	23.82
Back Gnd		140	121	145	119	138	126	131.50	10.89
NET COUNTS	0	24							20.20
Position	Z,	24	E20	506	570	526	E10	E20 00	20 47
Source+Plate counts		120	110	117	133	130	110	124 50	10.79
		130	110	114	100	150	119	114.50 A14.50	10.78 22.44
Basilian	0	26						~ / - //	2J. [4
FUSITION Source+Plate counts	Ζ,	20 502	566	542	570	616	588	570 00	25 AF
Source+Flate courts		112	130	104	1/0	117	157	424 67	17 70
		115	150	124	143		107	AA7 33	31.00
Position	2	28							
Source+Plate counts	٤,	591	626	609	581	641	618	611.00	22.26
Back Gnd		104	141	119	143	134	124	127.50	14.84
NET COUNTS		101		110				483.50	26.76
Position	2	30						h je berkenk	
Source+Plate coupts	Ξ,	620	600	593	584	611	570	596.33	18.14
Back Gnd		128	138	113	136	141	137	13217	10.34
NET COUNTS		120	100		100			464.17	20.88
Position	2	32							
Source+Plate counts	-,	639	632	590	616	648	663	631.33	25.63
Back Gnd		152	122	134	118	133	157	136.00	15.68
NET COUNTS							/	495.33	30.04
Position	2.	34							
Source+Plate counts	-1	623	659	612	624	643	661	637.00	20.43
Back Gnd		140	117	123	134	119	144	129.50	11.40
NET COUNTS								507.50	23.39

Data reduction and Fig.	: ²⁴¹ Am Source and Fuel	plate segment # 2 scan
Butu i cadotion and i ig	1 7411 VV 0/ VV 0110 1 001	plate eeginent n = eean

S.No	Position	Counts	St. deviation	Attenuation
1	212	674.50	38.88	0.6460
2	214	579.33	21.65	0.6960
3	216	514.50	22.62	0.7300
4	218	483.00	34.20	0.7465
5	220	465.00	34.20	0.7560
6	222	484.00	26.20	0.7460
7	224	414.50	23.14	0.7825
8	226	447.33	31.00	0.7652
9	228	483.50	26.76	0.7463
10	230	464.17	20.88	0.7564
13	232	495.33	30.04	0.7401
14	234	507.50	23.39	0.7337



Fig. 5: Preliminary results of fuel plate scan position 2

Appendix-II

Position 4, 12 MEAN STD.DEV, Source+Plate counts 537 498 502 495 538 563 522,17 27.81 Source+Plate counts 4, 140 132 127 150 130 144 135.17 27.81 386.00 22.22 Source+Plate counts 506 485 532 477 492 552 507.33 29.19 Jack Grid 130 133 126 136 150 144 136.60 8.99 Source+Plate counts 507 546 481 513 490 514.33 28.15 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Source+Plate counts 530 491 465 487 498 460 486.00 16.53 Source+Plate counts 530 491 465 486 501 444 460.01 16.53 341.00 28.24	Measured counting data	a: ²⁴¹ Am Sou	ırce a	nd Fu	el plate	seam	ent # 4	scan		~~~	
Source+Plate counts 537 498 502 495 538 663 522.17 27.81 Back Gnd 140 132 127 150 130 144 737.17 6.95 NET COUNTS 506 485 532 477 492 552 507.33 29.19 Sack Gnd 130 133 126 136 150 144 78.50 6.99 Source+Plate counts 506 485 532 477 492 552 507.33 29.19 Source+Plate counts 507 546 481 513 490 549 514.33 28.15 Source+Plate counts 507 546 481 513 460 488.50 25.24 Source+Plate counts 530 491 465 487 493 460 486.50 28.24 Source+Plate counts 533 151 142 170 132 167 147.50 13.85 Source+Plate coun	Position	4,	12							MEAN	TD.DEV.
Back Gnd 140 132 127 150 130 144 137.17 8.95 NET COUNTS	Source+Plate counts			537	498	502	495	538	563	522.17	27.81
NET COUNTS 4, 14 385.00 29.22 Position 4, 14 506 485 532 477 492 552 507.33 29.19 Back Gnd 130 133 126 136 150 144 136.50 8.98 NET COUNTS 507 546 481 513 490 549 514.33 28.15 Source+Plate counts 507 546 481 513 490 549 514.33 28.15 Source+Plate counts 500 491 465 487 498 460 488.50 25.24 Source+Plate counts 530 491 465 487 498 460 488.50 29.24 Position 4, 14 125 163 150 137 144.17 14.50 Source+Plate counts 549 458 508 496 563 480 577.33 41.16 Source+Plate counts 549 458 508	Back Gnd			140	132	127	150	130	144	137.17	8,95
Position 4, 14 506 485 532 477 492 552 507.33 29.19 Back Gnd 130 133 126 136 150 144 136.5 8.9 Position 4, 16 507 546 481 513 490 549 514.33 28.15 30.54 Source+Plate counts 507 546 481 513 490 549 514.33 22.07 Source+Plate counts 530 491 465 487 498 460 488.50 22.24 Source+Plate counts 530 491 465 487 498 460 488.50 22.24 Source+Plate counts 530 491 455 163 137 144.17 14.50 146 486.00 18.53 Soarce+Plate counts 485 507 495 464 501 147 14.750 147 Soarce+Plate counts 549 458	NET COUNTS									385.00	29.22
Source+Plate counts 506 485 532 477 492 552 507.33 29.19 Jack Gnd 130 133 126 136 150 144 736.50 8.98 Position 4 16 370.83 30.54 Source+Plate counts 507 546 481 513 490 549 541.433 28.15 Jack Gnd 114 142 148 113 136 118 128.50 15.36 Source+Plate counts 530 491 455 487 498 460 488.50 25.24 Source+Plate counts 530 491 455 487 498 460 486.50 25.24 Source+Plate counts 485 507 495 464 501 464 460.00 18.53 Jack Gnd 134 125 163 156 150 137 144.17 144.17 14.56 Source+Plate counts 549 458	Position	4.	14							김 사람이 한 것 같아.	
Back Gnd 130 133 126 136 150 144 136.50 8.98 NET COUNTS 5000000000000000000000000000000000000	Source+Plate counts	. 1		506	485	532	477	492	552	507.33	29.19
NET COUNTS 370.83 30.54 Position 4, 16 507 546 481 513 490 549 514.33 28.15 Back Gnd 114 142 148 113 136 118 128.50 15.36 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 518 539	Back Gnd			130	133	126	136	150	144	136.50	8.98
Position 4, 16 16 Source+Plate counts 507 546 481 513 490 549 514.33 28,15 Sack Gnd 114 142 148 113 136 118 128,50 15,36 Source+Plate counts 530 491 465 487 498 460 488,50 25,24 Jack Gnd 133 151 142 170 132 157 147,50 14,76 29,24 Position 4, 20 50urce+Plate counts 485 507 495 464 501 464 486,00 18,53 Source+Plate counts 485 507 495 464 501 464 486,00 18,53 Source+Plate counts 485 507 495 464 501 464 486,00 18,53 Source+Plate counts 549 458 508 486 563 480 507.33 41,16 39,83 34,343	NET COUNTS									370.83	30.54
Source+Plate counts 507 546 481 513 490 549 514.33 28.15 Back Gnd 114 142 148 113 136 118 128.50 15.36 NET COUNTS 385.83 32.07 385.83 32.07 Position 4, 18 113 136 118 128.50 15.36 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Position 4, 20 341.00 29.24 341.00 29.24 Position 4, 20 341.83 21.55 341.83 23.52 Position 4, 22 507 495 464 501 464 486.00 18.53 Position 4, 22 507 458 508 486 563 480 507.33 41.16 Back Gnd 157 141 150 167 143 127 147.50	Position	4	16								
Back Gnd 114 142 148 113 136 118 128.50 15.36 NET COUNTS 4, 18 385.83 32.07 Position 4, 18 133 151 142 170 132 157 147.50 14.76 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 549 458 508 486 563 480 507.33 41.47 Source+Plate counts 518 539 524 506 509 541 522.83 14.77 Source+Plate counts 51	Source+Plate counts	.,		507	546	481	513	490	549	514.33	28.15
NET COUNTS 11	Back Gnd			114	142	148	113	136	118	128.50	15.36
Position 4, 18 Concervation 4, 18 Source+Plate counts 530 491 465 487 498 460 488.50 25.24 Jack Gnd 133 151 142 170 132 157 147.50 147.75 Position 4, 20	NET COUNTS								110	385.83	32.07
Construct Figure Plate counts 530 491 465 487 498 460 488.50 25.24 Back Gnd 133 151 142 170 132 157 147.50 14.76 Position 4 20 341.00 29.24 341.00 29.24 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 485 507 495 464 501 464 486.00 18.53 Source+Plate counts 4. 22 341.83 23.52 341.83 23.52 Source+Plate counts 549 458 508 486 563 480 507.33 41.16 Back Gnd 157 141 150 167 143 127 147.50 13.83 Position 4 24 24 359.83 143.83 150 12.83 141.77 Source+Plate counts 518 <t< td=""><td>Position</td><td>4</td><td>18</td><td></td><td></td><td></td><td></td><td></td><td></td><td>000.00</td><td>02.07</td></t<>	Position	4	18							000.00	02.07
Source+Plate counts 530 491 465 467 493 460 26.20 26.20 Sack Gnd 133 151 142 170 132 157 147.50 147.60 Source+Plate counts 485 507 495 464 501 464 486.00 29.24 Position 4, 20		- ,	10	520	401	405	407	400	400	100 50	05.94
Jack Gnd 133 151 142 170 132 157 147.50 147.50 147.50 147.50 147.50 147.50 147.50 247.50 247.50 247.50 247.50 247.50 247.50 247.50 29.24 Position 4 20 20 341.00 29.24 29.24 29.24 29.24 20 29.24 20 29.24 20 29.24 20 29.24 20 29.24 20 29.24 29.24 29.24 29.24 29.24 29.25 29.24 20 29.24 29.24 29.24 29.25 29.25 29.25 29.26 29	Source+Plate counts			530	491	400	407	490	460	466.30	20.24
NET COUNTS 341,00 29,24 Source+Plate counts 485 507 495 464 501 464 486.00 18,53 Back Gnd 134 125 163 156 150 137 144,17 14,50 Source+Plate counts 549 458 508 486 563 480 507,33 41,16 Source+Plate counts 549 458 508 486 563 480 507,33 41,16 Back Gnd 157 141 150 167 143 127 147,50 13,85 Source+Plate counts 518 539 524 506 509 541 522,83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12,85 NET COUNTS 512 488 476 533 494 510 502,17 20,30 Back Gnd 140 147 132 143 136 153	Back Gnd			133	151	142	170	132	157	147.50	14.70
Position 4, 20 Source+Plate counts 485<507	NETCOUNTS									341.00	. 29.24
Source+Plate counts 485 507 495 464 501 464 4466.00 78.53 Back Gnd 134 125 163 156 150 137 144.17 145.0 Position 4, 22 341.83 23.52 341.83 23.52 Position 4, 22 549 458 508 486 563 480 507.33 41.16 Back Gnd 157 141 150 167 143 127 147.50 13.85 Position 4, 24 518 539 524 506 509 541 522.83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12.85 Source+Plate counts 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 12.17 20.30 Back Gnd 152 145 127 148 163 139 145.67	Position	4,	20		- 0 7						a an
Jack Grid 134 125 163 156 150 137 144,17 14,50 NET COUNTS 341,63 23,52 Position 4, 22 341,63 23,52 Source+Plate counts 549 458 508 486 563 480 507,33 41,16 Back Gnd 157 141 150 167 143 127 147,50 13,85 Source+Plate counts 518 539 524 506 509 541 522,83 14,77 Back Gnd 140 136 156 172 147 149 150.00 12,85 NET COUNTS 512 488 476 533 494 510 502,17 20,30 Back Gnd 140 147 132 143 136 153 141,83 7,57 NET COUNTS 518 474 465 555 488 496 499,33 32,89 Back Gnd 152 145 127 148 163 139 145,67 12,16 <td>Source+Plate counts</td> <td></td> <td></td> <td>485</td> <td>507</td> <td>495</td> <td>464</td> <td>501</td> <td>464</td> <td>486.00</td> <td>18.53</td>	Source+Plate counts			485	507	495	464	501	464	486.00	18.53
NET COUNTS 341.83 23.52 Position 4, 22 549 458 508 486 563 480 507.33 41.16 Back Gnd 157 141 150 167 143 127 147.50 13.85 NET COUNTS 518 539 524 506 509 541 522.83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12.85 NET COUNTS 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 518 474 465 555 488 496 499.33 32.89 Source+Plate counts 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 <t< td=""><td>Back Gnd</td><td></td><td></td><td>134</td><td>125</td><td>163</td><td>156</td><td>150</td><td>137</td><td>144.17</td><td>14.50</td></t<>	Back Gnd			134	125	163	156	150	137	144.17	14.50
Position 4, 22 Source+Plate counts 549 458 508 486 563 480 507.33 41.16 Back Gnd 157 141 150 167 143 127 147.50 13.85 NET COUNTS 518 539 524 506 509 541 522.83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12.85 NET COUNTS 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 512 488 476 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.167 NET COUNTS 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 142.67 12.16 NET COUNTS 7 Position 4, 28 Source+Plate counts 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 7 Position 4, 30 Source+Plate counts 4, 32 Source+Plate counts 4, 34 Source+Plate counts 489 458 471 491 508 454 478.50 21.04	NET COUNTS									341.83	23.52
Source+Plate counts 549 458 508 486 563 480 507,33 41,16 Back Gnd 157 141 150 167 143 127 147,50 13,85 Position 4, 24 359,83 43,43 343 343,43 Position 4, 24 518 539 524 506 509 541 522,83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12.85 NET COUNTS 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141,83 7.57 NET COUNTS 512 488 476 553 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141,83 7.57 Position 4, 28 500 502.17 20.30 360.33 21.67 Source+Plate counts	Position	4,	22								ator de te
Back Gnd 157 141 150 167 143 127 147.50 13.85 NET COUNTS 4, 24 359.83 43.43 Position 4, 24 518 539 524 506 509 541 522.83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12.85 NET COUNTS 140 136 156 172 147 149 150.00 12.85 Source+Plate counts 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 Position 4, 28 26 360.33 21.67 360.33 21.67 Position 4, 28 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS <t< td=""><td>Source+Plate counts</td><td></td><td></td><td>549</td><td>458</td><td>508</td><td>486</td><td>563</td><td>480</td><td>507.33</td><td>41.16</td></t<>	Source+Plate counts			549	458	508	486	563	480	507.33	41.16
NET COUNTS 359,83 43,43 Position 4,24 518<539	Back Gnd			157	141	150	167	143	127	147.50	13.85
Position 4, 24 Source+Plate counts 518<539<524<506	NET COUNTS									. 359,83	43.43
Source+Plate counts 518 539 524 506 509 541 522.83 14.77 Back Gnd 140 136 156 172 147 149 150.00 12.85 NET COUNTS 372.83 19.58 Position 4, 26 372.83 19.58 Source+Plate counts 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 140 147 132 143 136 153 141.83 7.57 Back Gnd 140 147 132 143 136 153 141.83 7.57 Res Gnd 4, 28 500 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 499 465 477 525 484 500 491.67 21.07	Position	4,	24							Service and the service of the	
Back Gnd 140 136 156 172 147 149 150.00 12.85 NET COUNTS 372.83 19.58 Position 4, 26 372.83 19.58 Source+Plate counts 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 140 147 132 143 136 153 141.83 7.57 NET COUNTS 4, 28 360.33 21.67 360.33 21.67 Position 4, 28 360.33 32.89 35.06 Source+Plate counts 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 499 465 477 525 484 500 491.67 21.07 Back Gnd 158 139 156	Source+Plate counts			518	539	524	506	509	541	522.83	14.77
NET COUNTS 372.83 19.58 Position 4, 26 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 7 28 360.33 21.67 360.33 21.67 Position 4, 28 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 518 474 465 555 484 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 499 465 477 525 484 500 491.67 21.07 Back Gnd 158 139 156 153 129 119 142.33 <t< td=""><td>Back Gnd</td><td></td><td></td><td>140</td><td>136</td><td>156</td><td>172</td><td>147</td><td>149</td><td>150.00</td><td>12.85</td></t<>	Back Gnd			140	136	156	172	147	149	150.00	12.85
Position 4, 26 Source+Plate counts 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 7 28 360.33 21.67 360.33 21.67 Position 4, 28 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 502.17 21.05 353.67 35.06 35.06 12.16 143.13 149.163	NET COUNTS									372.83	19.58
Source+Plate counts 512 488 476 533 494 510 502.17 20.30 Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 7 20.30 360.33 21.67 360.33 21.67 Position 4, 28 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 7 525 484 500 491.67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 30 32 32.89 349.33 26.45 349.33 26.45 Position 4, 30 32 33 32.89 349.33 26.45 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 <td< td=""><td>Position</td><td>4,</td><td>26</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>	Position	4,	26								
Back Gnd 140 147 132 143 136 153 141.83 7.57 NET COUNTS 4, 28 360.33 21.67 360.33 21.67 Source+Plate counts 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 518 474 465 455 484 500 499.33 32.89 Position 4, 30 353.67 35.06 353.67 35.06 Position 4, 30 39 156 153 129 119 142.33 16.00 Source+Plate counts 499 465 477 525 484 500 491.67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 32 32 33 26.45 349.33 26.45 Position 4, 32<	Source+Plate counts			512	488	476	533	494	510	502.17	20,30
NET COUNTS 360.33 21.67 Position 4, 28 28 350.00000000000000000000000000000000000	Back Gnd			140	147	132	143	136	153	141.83	7.57
Position 4, 28 Source+Plate counts 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 152 145 127 148 163 139 145.67 12.16 Position 4, 30 30 353.67 35.06 Source+Plate counts 499 465 477 525 484 500 491.67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 32 32.89 349.33 26.45 Position 4, 32 32 349.33 26.45 349.33 26.45 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS	NET COUNTS									360.33	21.67
Source+Plate counts 518 474 465 555 488 496 499.33 32.89 Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 152 145 127 148 163 139 145.67 12.16 Position 4, 30 158 477 525 484 500 491,67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 32.89 349.33 26.45 Position 4, 32 32.89 349.33 26.45 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 4, 34 348.33 24.06 348.33 24.06 Position 4, 34 348 348.33 24.06 <	Position	4,	28								
Back Gnd 152 145 127 148 163 139 145.67 12.16 NET COUNTS 4, 30 30 353.67 35.06 Source+Plate counts 499 465 477 525 484 500 491,67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 32 349.33 26.45 349.33 26.45 Position 4, 32 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 4, 34 34 34 348.33 24.06 Position 4, 34 489 458 471 491 508 454 478.50 21.04	Source+Plate counts			518	474	465	555	488	496	499.33	32.89
NET COUNTS 353.67 35.06 Position 4, 30 30 499 465 477 525 484 500 491.67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 158 139 156 153 129 119 142.33 16.00 NET COUNTS 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 Source+Plate counts 4, 34 34 34 348.33 24.06 Position 4, 34 489 458 471 491 508 454 478.50 21.04	Back Gnd			152	145	127	148	163	139	145.67	12.16
Position 4, 30 Source+Plate counts 499 465 477 525 484 500 491,67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 26.45 349.33 26.45 26.45 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 348.33 24.06 348.33 24.06 348.33 24.06 Position 4, 34 489 458 471 491 508 454 478.50 21.04	NET COUNTS									353.67	35.06
Source+Plate counts 499 465 477 525 484 500 491,67 21.07 Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 32 349.33 26.45 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 348.33 24.06 348.33 24.06 Position 4, 34 489 458 471 491 508 454 478.50 21.04	Position	4,	30								
Back Gnd 158 139 156 153 129 119 142.33 16.00 NET COUNTS 4, 32 32 349.33 26.45 Position 4, 32 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 168 149 131 134 147 129 143.00 14.82 NET COUNTS 348.33 24.06 348.33 24.06 Position 4, 34 458 471 491 508 454 478.50 21.04	Source+Plate counts			499	465	477	525	484	500	491.67	21.07
NET COUNTS 349:33 26.45 Position 4, 32 32 32 33 26.45 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 348.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 348.33 24.06 NET COUNTS 4, 34 34 34 34 34 34 Source+Plate counts 489 458 471 491 508 454 478.50 21.04 34	Back Gnd			158	139	156	153	129	119	142.33	16.00
Position 4, 32 Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 348.33 24.06 Position 4, 34 Source+Plate counts 489 458 471 491 508 454 478.50 21.04	NET COUNTS									349.33	26.45
Source+Plate counts 462 479 516 495 504 492 491.33 18.95 Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 348.33 24.06 24.06 24.04 24.06 24.06 Position 4, 34 34 34.05 348.50 21.04	Position	4,	32							 The second system is a second system in the second system in the second system is a second system in the second system in the second system is a second system in the second system in t	
Back Gnd 168 149 131 134 147 129 143.00 14.82 NET COUNTS 348.33 24.06	Source+Plate counts			462	479	516	495	504	492	491.33	18.95
NET COUNTS 348.33 24.06 Position 4, 34 24.06 24.06 Source+Plate counts 489 458 471 491 508 454 478.50 21.04	Back Gnd			168	149	131	134	147	129	143.00	14.82
Position 4, 34 Source+Plate counts 489 458 471 491 508 454 478.50 21.04	NET COUNTS									348.33	24.06
Source+Plate counts 489 458 471 491 508 454 478.50 21.04	Position	4.	34							an a	
	Source+Plate counts	• •		489	458	471	491	508	454	478.50	21.04
Back Gnd 129 142 134 146 176 153 146.67 16.71	Back Gnd			129	142	134	146	176	153	146.67	16.71
NET COUNTS 331.83 26.87	NET COUNTS									331.83	26.87

NET COUNTS

S.No	Position	Counts	St. deviation	Attenuation
1	412	385.00	29.22	0.7980
2	414	370.83	30.54	0.8054
3	416	385.83	32.07	0.7975
4	418	341.00	29.24	0.8210
5	420	341.83	23.52	0.8206
6	422	359.83	43.43	0.8112
7	424	372.83	19.58	0.8043
8	426	360.33	21.67	0.8109
9	428	353.67	35.06	0.8144
10	430	349.33	26.45	0.8167
13	432	348.33	24.06	0.8172
14	434	331.83	26.87	0.8259
10 13 14	430 432 434	349.33 348.33 331.83	26.45 24.06 26.87	0.8167 0.8172 0.8259

Data reduction and Fig 2: ²⁴¹Am Source and Fuel plate segment # 4 scan



Fig. 6: Preliminary results of fuel plate scan position 4

Measured counting data: ²⁴¹Am Source and Fuel plate segment # 6 scan

Å

Position	6,	12						MEAN	STD.DEV.
Source+Plate counts		490	527	529	494	451	459	491.67	32.78
Back Gnd		124	127	139	142	107	140	129.83	13.41
NET COUNTS								361.83	35.41
Position	6,	14							
Source+Plate counts		482	501	515	540	495	510	507.17	19.83
Back Gnd		134	113	140	135	141	132	132.50	10.17
NET COUNTS								374.67	22.29
Position	6,	16							
Source+Plate counts		474	503	501	502	512	495	497.83	12.89
Back Gnd		155	132	135	147	163	161	148.83	13.15
NET COUNTS							1 	349.00	18.42
Position	6,	18						ан ал ал ар ал ар ар	
Source+Plate counts		483	438	484	536	508	504	492.17	32.85
Back Gnd		158	141	124	112	137	121 🖗	132.17	16.53
NET COUNTS							50 17 18	360.00	36.78
Position	6,	20						이가 사람이 가지 않는 것이라는 것이 가지 않다. 이 가지 않는 것이 같은 것이 같이 있는 것이 같이 있다. 같은 것이 같은 것이 같은 것이 같이 있는 것이 같이 있는 것이 같이 있다.	
Source+Plate counts		492	508	451	474	512	463 💡	483.33	24.70
Back Gnd		150	145	115	128	139	142	136.50	12.85
NET COUNTS									27.85
Position	6,	22							
Source+Plate counts		472	462	495	481	493	484	481.17	12.58
Back Gnd		126	136	116	128	117	149	128.67	12.42
NET COUNTS								352.50	17.68
Position	6,	24			•				
Source+Plate counts		521	471	504	521	496	490	500.50	19.25
Back Gnd		137	130	127	149	130	141	135.67	8.33
NET COUNTS								364.83	20.98
Position	6,	26					5.4 1		
Source+Plate counts		480	479	496	491	486	528	493.33	18.17
Back Gnd		153	123	140	128	126	136 💡	134.33	11.15
NET COUNTS								359.00	21.32
Position	6,	28					ħ		Net at a globa
Source+Plate counts		533	509	518	511	457	517	507.50	26.14
Back Gnd		132	125	112	131	130	137	127.83	8.66
NET COUNTS								379.67	27.53
Position	6,	30					-	가지 아이에 바람이다. 이 아이에 아이에 아이에 아이에 아이에 아이에 아이에 아이에 아이에 아이	
Source+Plate counts		478	540	491	487	472	486	492.33	24.34
Back Gnd		135	130	135	138	136	123	132.83	5.49
NET COUNTS								359.50	24.95
Position	6,	32							
Source+Plate counts		470	465	456	463	465	470	464.83	5.19
Back Gnd		120	129	124	122	121	116	122.00	4.34
NET COUNTS								342.83	6.77
Position	6,	34						一個語語をつい	
Source+Plate counts		444	487	466	485	499	500	480.17	21.57
Back Gnd		101	114	117	118	126	139	119,17	12.67
NET COUNTS								361.00	25.02

Appendix-III

S.No	Position	Counts	St. deviation	Attenuation
1	612	361.83	35.41	0.8101
2	614	374.67	22.29	0.8034
3	616	349.00	18.42	0.8168
4	618	360.00	36.78	0.8111
5	620	346.83	27.85	0.8180
6	622	352.50	17.68	0.8150
7	624	364.83	20.98	0.8085
8	626	359.00	21.32	0.8116
9	628	379.67	27.53	0.8008
10	630	359.50	24.95	0.8113
13	632	342.83	6.77	0.8201
14	634	361.00	25.02	0.8105

Data reduction and Fig 3: ²⁴¹ Am Source and Fuel plate segment # 6 scan



Fig. 7: Preliminary results of fuel plate scan position 6

Mossured counting data; 24	¹ Am Source a	nd Evel plate (
measured counting data:	Am Source al	<u>no r-uel plate s</u>	<u>segment # 8 scan</u>

Appendix-IV

Position	8, 12						MEAN	STD.DEV.
Source+Plate counts	1127	1365	1354	1352	1303		1300.20	99.73
Back Gnd	102	91	88	110	98	105	99.00	8.39
NET COUNTS							1201.20	100.08
Position	8, 14							
Source+Plate counts	1394	1495	1370	1284	1332	1370	1374.17	70.62
Back Gnd	117	97	65	85	87	94	90.83	17.02
NET COUNTS							1283.33	72.64
Position	8, 16							$g = e^{-\frac{1}{2}} + $
Source+Plate counts	1390	1595	1352	1366	1467	1436	1434.33	89.77
Back Gnd	104	103	108	94	106	90	100.83	7.17
NET COUNTS							1333.50	90.06
Position	8, 18						- 그 같은 것은 것은 것은 것이다. - 성상은 것 이태와 도시 등 것이다.	
Source+Plate counts	1497	1543	1526	1438	146 1	1465	1488.33	40.76
Back Gnd	93	104	113	108	89	94	100.17	9.54
NET COUNTS							1388.17	41.86
Position	8, 20							
Source+Plate counts	1561	1660	1532	1634	1567	1584	1589.67	48.18
Back Gnd	99	106	92	73	109	103	97.00	13.16
NET COUNTS							1492.67	49.94
Position	8, 22							
Source+Plate counts	1503	1509	1444	1339	1394	1519	1451.33	72.85
Back Gnd	88	106	95	100	95	109	98.83	7.78
NET COUNTS							1352.50	73.26
Position	8, 24							
Source+Plate counts	1550	1528	1607	1610	1575	1502	1562.00	43.35
Back Gnd	89	85	83	101	87	91	89.33	6.38
NET COUNTS							1472.67	43.82
Position	8, 26							An an Anna a' l
Source+Plate counts	1648	1616	1649	1651	1669	1637	1645.00	17.56
Back Gnd	88	79	101	95	93	91	1449 1 -1/4	/.39
NET COUNTS	0.00						. 1553.83	79.05
Position	8, 28	4005	4004	4004				
Source+Plate counts	1705	1695	1691	1684	1/46	1699	1703.33	22.08
Back Gnd	81	75	99	92	84	84	85.83	8.47
NET COUNTS	0 00						1617.50	23.65
Position	8, 30	4000	4000	4000	4044	1004	4050 07	<u> </u>
Source+Plate counts	1686	1696	1630	1608	1641	1661	7653.07	33.70
	70	65	93	90	107	103	93.33	11.47
NET COUNTS	0 22						1500.33	35.05
Position Source+Plote coupte	0, 32	1671	1666	1561	1642	1692	4629.00	16 02
Source+Plate counts	1004	1071	1000	1001	1043	1003	1038.00	40.92
	03	10	100	99	97	108	95.50 4540 50	12.37
NET COUNTS	NC Q						1344.30	40.3/
FUSILIUN Source+Dista source	0, 04	1005	1600	1000	404E	4700	THE REAL PROPERTY OF	оран (р. с.
	1089	00	1000	2001	0101	1/20	1080.17	JJ.UJ
	80	92	11	02	90	103	80.07 1E03 E0	9.04
NET COUNTS							1083.00	30.30

S.No	Position	Counts	St. deviation	Attenuation
1	812	1201.20	100.08	0.3696
2	814	1283.33	72.64	0.3265
3	816	1333.50	90.06	0.3002
4	818	1388.17	41.86	0.2715
5	820	1492.67	49.94	0.2167
6	822	1352.50	73.26	0.2902
7	824	1472.67	43.82	0.2271
8	826	1553.83	19.05	0.1846
9	828	1617.50	23.65	0.1511
10	830	1560.33	35.65	0.1811
13	832	1542.50	48.57	0.1905
14	834	1593.50	36.30	0.1637

Data reduction and Fig 4: ²⁴¹Am Source and Fuel plate segment # 8 scan



Fig. 8: Preliminary results of fuel plate scan position 8