PINSTECH-208

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

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Abstract

The R & D work to establish a facility for the study of homogeneity and fuel density i.e., quantity of ^{235}U 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 NaI detector has been established. The fuel plate (U_3Si_2-Al) was manually scanned and the transmission of gamma radiation from radioactive ^{241}Am 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. Introduction

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_oC^2.

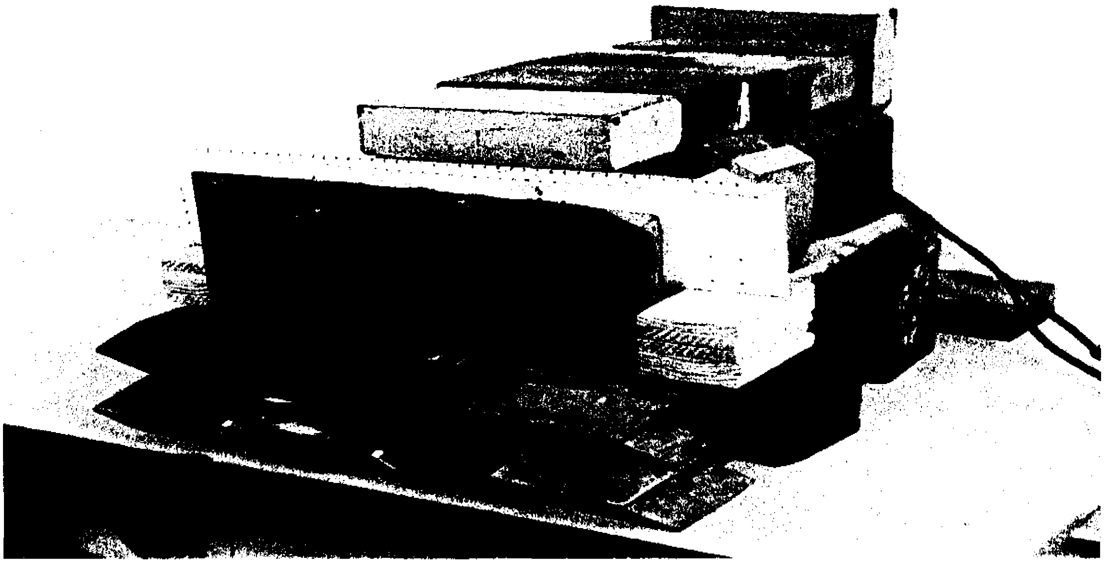
All the above mentioned processes contribute to the complex gamma ray spectrum, especially for the multi gamma emitting nuclides. Based on gamma ray interaction and attenuation phenomenon, gamma ray scanners can be designed. The design and development work of the gamma ray scanner for homogeneity measurement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

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

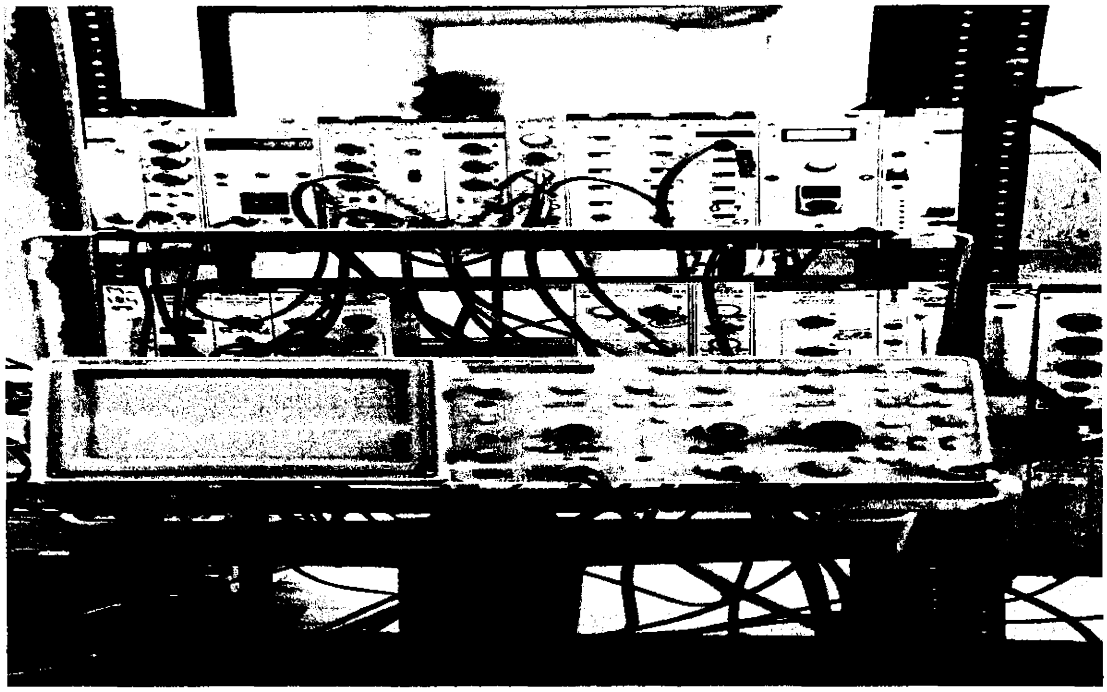
In order to develop a gamma ray scanning system, the following facilities were established at PINSTECH.

- *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 ^{241}Am 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(Tl) 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 ^{241}Am 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)



(b)

Fig.1 : (a) Gamma ray scanning system (b) Allied electronic circuitry of the gamma ray scanning system

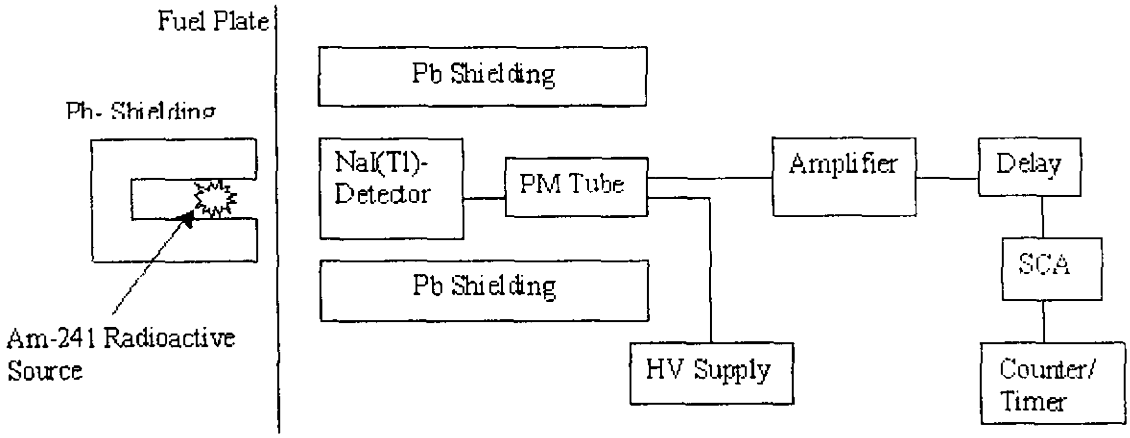


Fig.2 : Block diagram of the gamma ray Scanning system

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.

<u>Segment</u> **<u>Measuring positions</u>**

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)

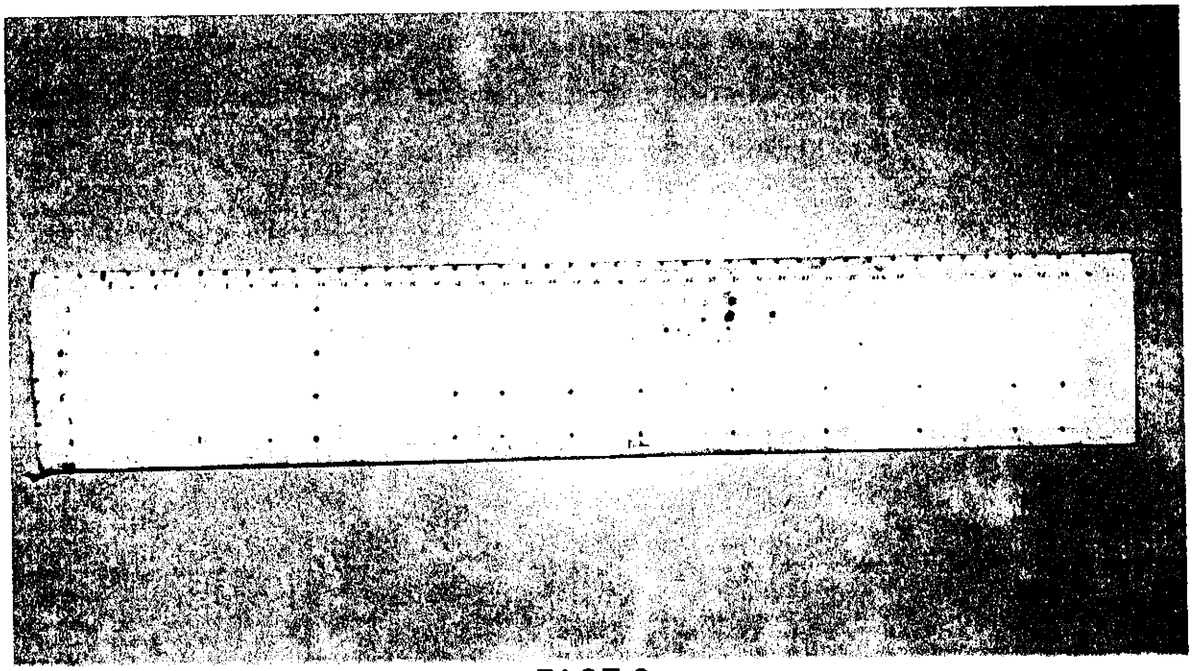
Segment # 6: (6, 12), (6, 14), (6, 16), (6, 18), (6, 20), (6, 22), (6, 24), (6, 26), (6, 28), (6, 30), (6, 32), (6, 34)

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 re-measurements.

The radioactive source of ^{241}Am (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.

(a) FACE-1



(b) FACE-2

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

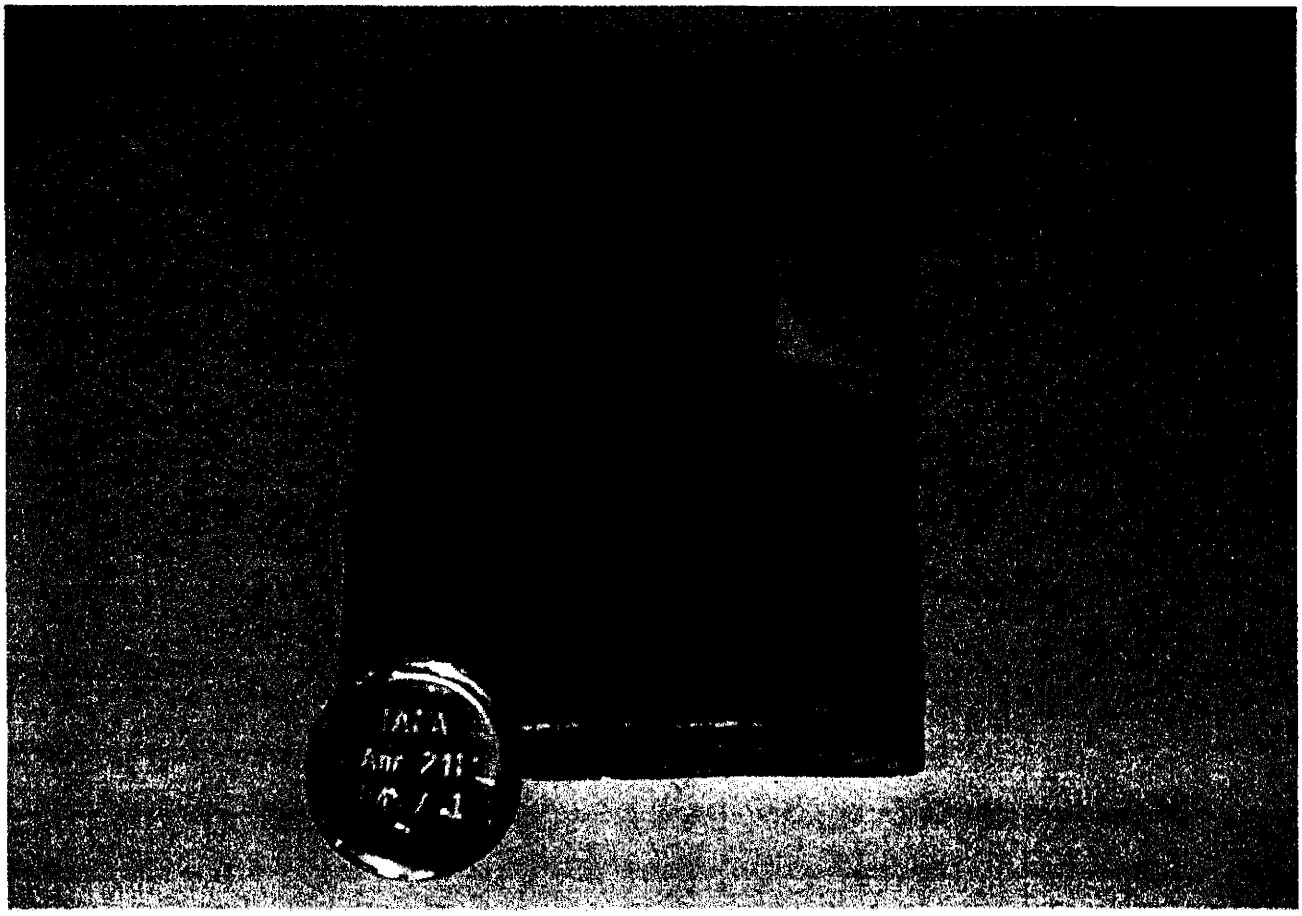


Fig 4. IAEA radioactive standard source (Am-241) and the locally fabricated source holder.

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 ^{241}Am 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 ^{235}U are also required to see the possibility of ^{235}U quantification in the fuel plates.

5. References

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

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APPENDICES

Appendix-I

Measured counting data of ^{241}*Am Source - Fuel plate segment # 2 scan*

Source counts		1871	1930	1845	1886	1827	1976	1918	1928
		1889	1911	1963	1939	1946	1885	1883	1891
	Average (Above counts) :				1905.50	40.93			

In the following lines: Col. 2 to 6 (after "Position" row contains the data counts)

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							
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							
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	***615.50***	***23.82***
Back Gnd		140	121	145	119	138	126	***131.50***	***10.89***
NET COUNTS								***484.00***	***26.20***
Position	2,	24							
Source+Plate counts		549	539	526	572	536	512	***539.00***	***20.47***
Back Gnd		138	110	117	133	130	119	***124.50***	***10.78***
NET COUNTS								***414.50***	***23.14***
Position	2,	26							
Source+Plate counts		592	566	542	570	616	588	***579.00***	***25.45***
Back Gnd		113	130	124	149	117	157	***131.67***	***17.70***
NET COUNTS								***447.33***	***31.00***
Position	2,	28							
Source+Plate counts		591	626	609	581	641	618	***611.00***	***22.26***
Back Gnd		104	141	119	143	134	124	***127.50***	***14.84***
NET COUNTS								***483.50***	***26.76***
Position	2,	30							
Source+Plate counts		620	600	593	584	611	570	***596.33***	***18.14***
Back Gnd		128	138	113	136	141	137	***132.17***	***10.34***
NET COUNTS								***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		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 1: ^{241}*Am Source and Fuel plate segment # 2 scan*

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

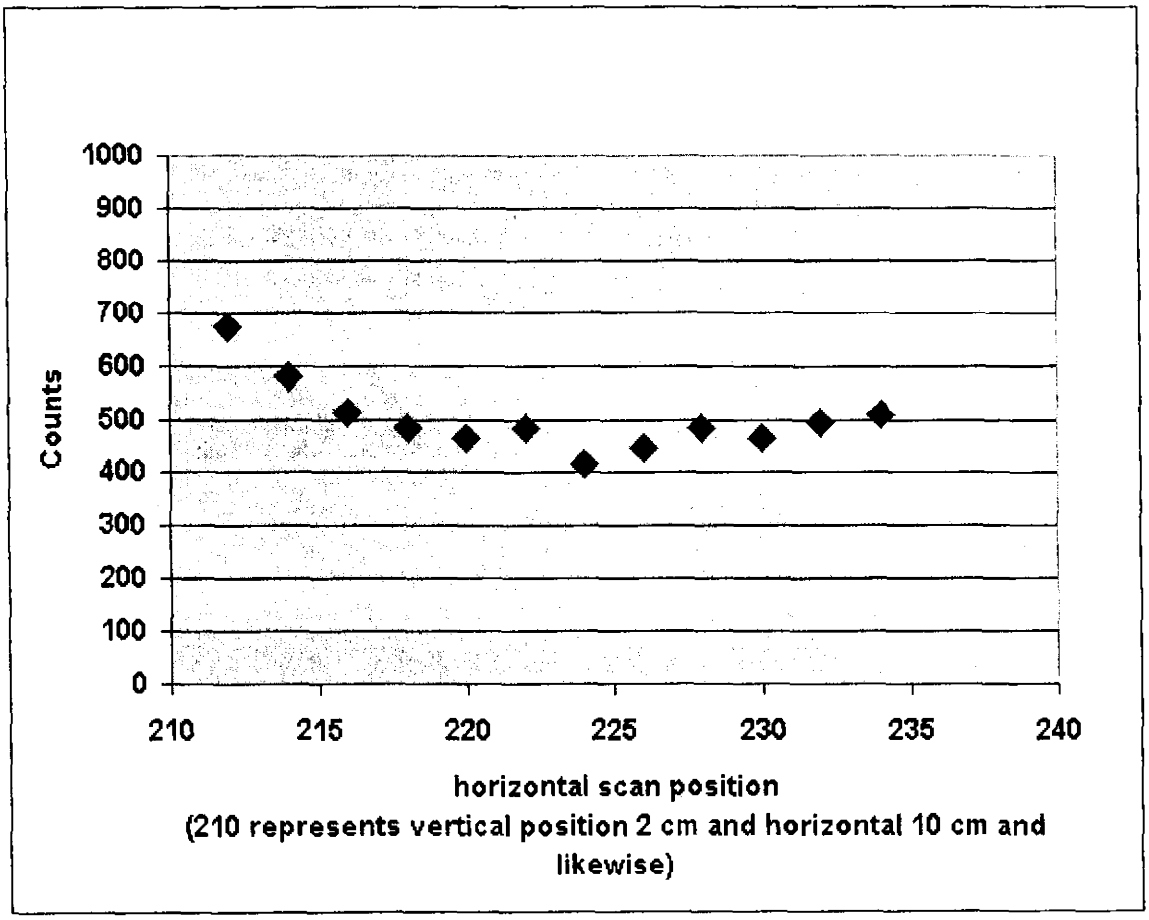

Fig. 5: Preliminary results of fuel plate scan position 2

Appendix-II

Measured counting data: ^{241}*Am Source and Fuel plate segment # 4 scan*

									MEAN	STD.DEV.
Position	4,	12								
Source+Plate counts			537	498	502	495	538	563	***522.17***	***27.81***
Back Gnd			140	132	127	150	130	144	***137.17***	***8.95***
NET COUNTS									***385.00***	***29.22***
Position	4,	14								
Source+Plate counts			506	485	532	477	492	552	***507.33***	***29.19***
Back Gnd			130	133	126	136	150	144	***136.50***	***8.98***
NET COUNTS									***370.83***	***30.54***
Position	4,	16								
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***
Position	4,	18								
Source+Plate counts			530	491	465	487	498	460	***488.50***	***25.24***
Back Gnd			133	151	142	170	132	157	***147.50***	***14.76***
NET COUNTS									***341.00***	***29.24***
Position	4,	20								
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***
NET COUNTS									***341.83***	***23.52***
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									***359.83***	***43.43***
Position	4,	24								
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								
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									***360.33***	***21.67***
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									***353.67***	***35.06***
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									***349.33***	***26.45***
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***
Back Gnd			129	142	134	146	176	153	***146.67***	***16.71***
NET COUNTS									***331.83***	***26.87***

Data reduction and Fig 2: ^{241}*Am Source and Fuel plate segment # 4 scan*

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

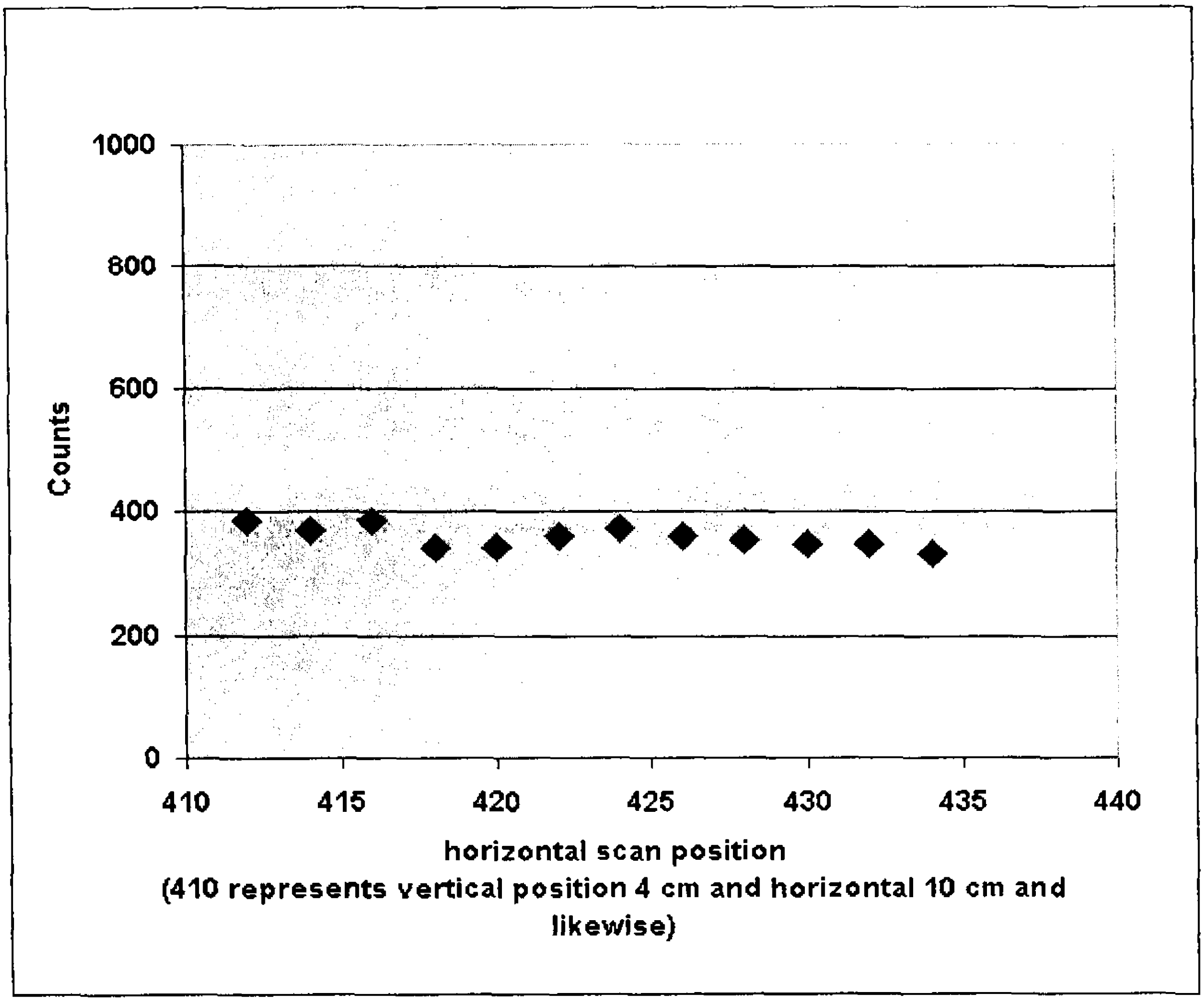

Fig. 6: Preliminary results of fuel plate scan position 4

Measured counting data: ^{241}*Am Source and Fuel plate segment # 6 scan*

								MEAN	STD.DEV.
Position	6, 12								
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								*349.00*	*18.42*
Position	6, 18								
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								*360.00*	*36.78*
Position	6, 20								
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								*346.83*	*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								
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								
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								
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								
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*

Data reduction and Fig 3: ^{241}*Am Source and Fuel plate segment # 6 scan*

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

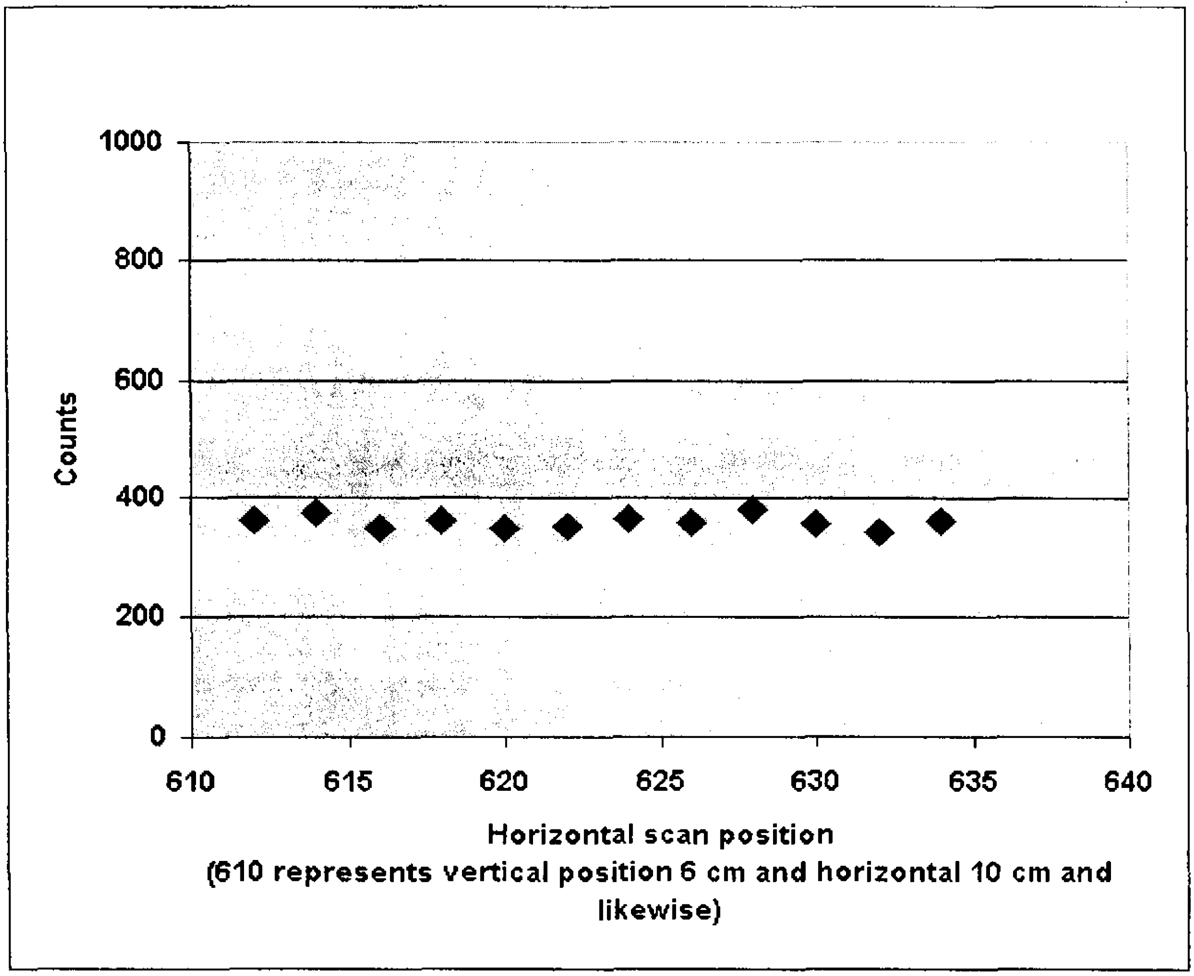

Fig. 7: Preliminary results of fuel plate scan position 6

Measured counting data: ^{241}*Am Source and Fuel plate segment # 8 scan*

							MEAN	STD.DEV.
Position	8, 12							
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							
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							
Source+Plate counts	1497	1543	1526	1438	1461	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							
Source+Plate counts	1648	1616	1649	1651	1669	1637	***1645.00***	***17.56***
Back Gnd	88	79	101	95	93	91	***91.17***	***7.39***
NET COUNTS							***1553.83***	***19.05***
Position	8, 28							
Source+Plate counts	1705	1695	1691	1684	1746	1699	***1703.33***	***22.08***
Back Gnd	81	75	99	92	84	84	***85.83***	***8.47***
NET COUNTS							***1617.50***	***23.65***
Position	8, 30							
Source+Plate counts	1686	1696	1630	1608	1641	1661	***1653.67***	***33.76***
Back Gnd	76	85	93	96	107	103	***93.33***	***11.47***
NET COUNTS							***1560.33***	***35.65***
Position	8, 32							
Source+Plate counts	1604	1671	1666	1561	1643	1683	***1638.00***	***46.92***
Back Gnd	83	78	108	99	97	108	***95.50***	***12.57***
NET COUNTS							***1542.50***	***48.57***
Position	8, 34							
Source+Plate counts	1689	1695	1680	1682	1615	1720	***1680.17***	***35.03***
Back Gnd	80	92	77	82	86	103	***86.67***	***9.54***
NET COUNTS							***1593.50***	***36.30***

Data reduction and Fig 4: ^{241}*Am Source and Fuel plate segment # 8 scan*

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

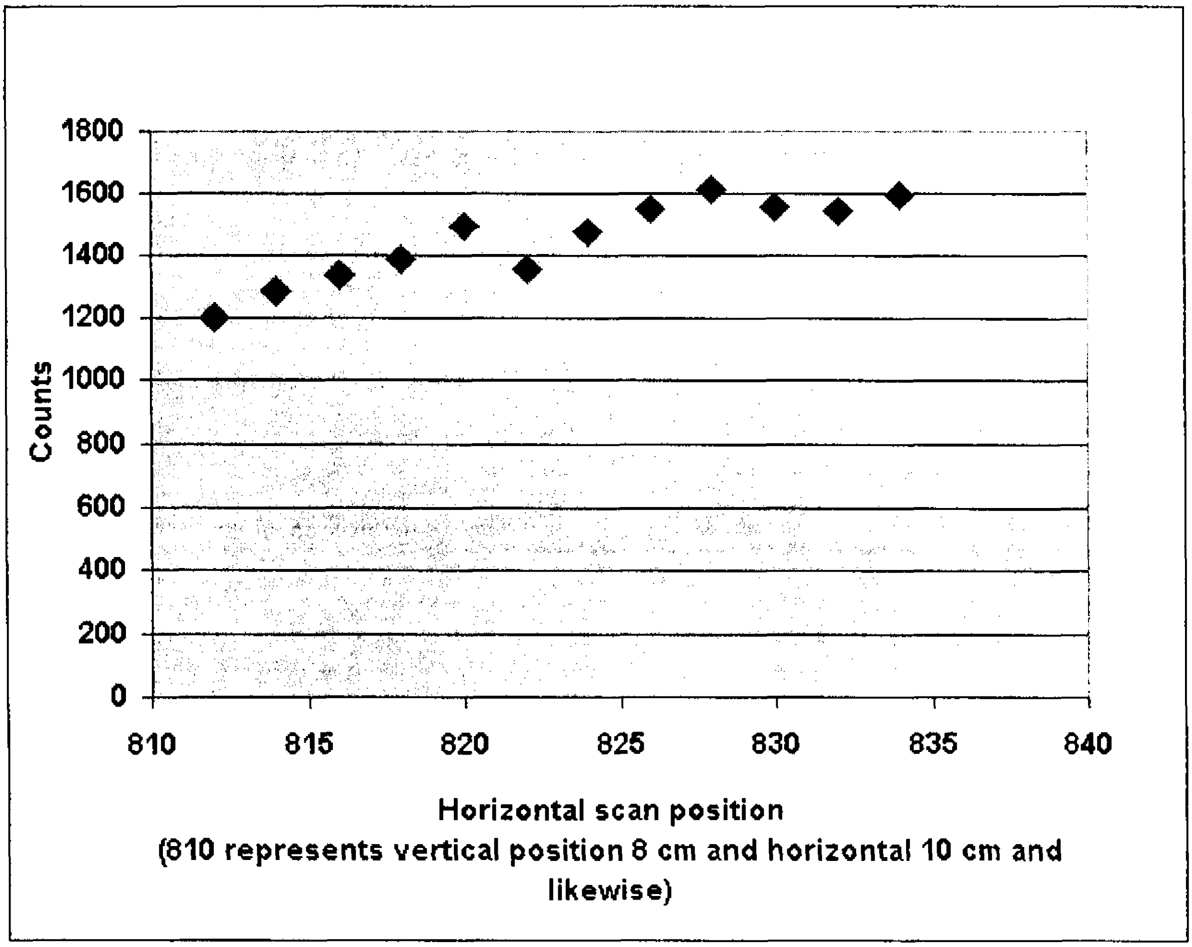

Fig. 8: Preliminary results of fuel plate scan position 8