1 Title:

Adept Medical X-Ray Shield: Scatter Radiation Shielding Grid Format Methodology

2 Background:

Adept Medical X-Ray Shield (X-Ray Shield) is embedded with 0.5mm Lead (pb), offering protection from scatter radiation for operators. To verify this, testing was carried out to measure the product's effectiveness in a controlled environment to simulate scatter radiation exposure around a gridded pattern.

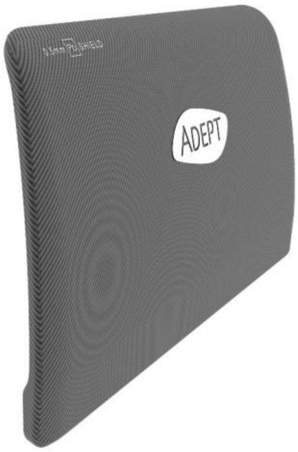

Figure 1 Adept Medical X-Ray Shield

3 Scope:

The aim of this test is to measure the level of scatter radiation with and without the X-ray Shield over multiple gridded point, providing a comparison in amount of scatter radiation protection and the reduction the X-ray Shield offers to operators. The methodology is designed to examine purely the impact of the X-ray Shield on extent of scatter radiation.

4 Method:

The testing was conducted at Auckland District Health Board Interventional Cardiology Laboratory's on a Siemens Artis Imaging Table. The measurements were recorded by Brian Lunt, Medical Physicist.

A radiographic human torso phantom was used to simulate a patient on the table and provides the primary source of radiation to the clinician and staff via scatter.

Below is an image of the X-ray Shield showing dimensions of the vertical portion containing the 0.5mm Lead.

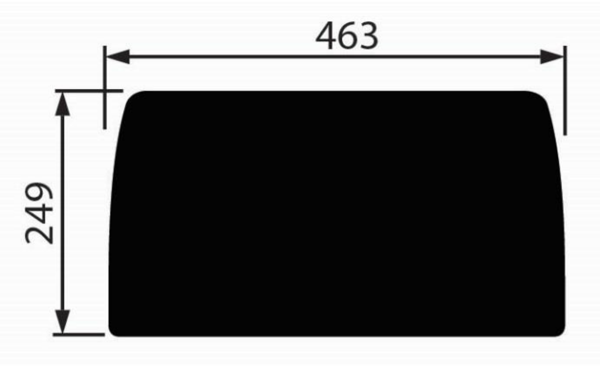

Figure 2 - Adept Medical X-Ray Shield Dimensions

Further details listed below are constant test parameters that were consistent in all measurements. In addition to these, the intensifier height, beam intensity, beam quality (automatic) and gantry tilt (independent variable) were changed.

Table 1 - Constant parameters during the testing of the X-ray Shield

Technique	
Scatter Source	Rando Human Torso Phantom
C-Arm Model	Siemens Artis Q-Zen
Digital Procedure Selection	Coronaries/ HDR CARE Minus
Beam Quality (KVp)	80±5
Image Table Width at Shield	45 cm
Image Table Height	90 cm
Source Image Distance	100 cm
Exposure Time	10 Seconds
Frames / second	15
Air Gap	15 cm
Scatter Mode	Integrate
Camera Field of View	20cm
Dosimeter Model	Unfors Xi

The digital procedure selection determines the output parameters such as beam quality and intensity. These changes automatically depending on the angle of the C-Arm.

The Human phantom was placed centrally to the Imaging Table with the X-Ray camera centralised to this on both X and Y axis. The Shield was positioned with vertical shield portion at side of table. It was aligned to the centre of the phantom and X-Ray camera.

The Dosimeter was placed at differing height / distance locations from the centre reference at 20 cm intervals about a grid and always 55 cm out from centre of the Imaging Table.

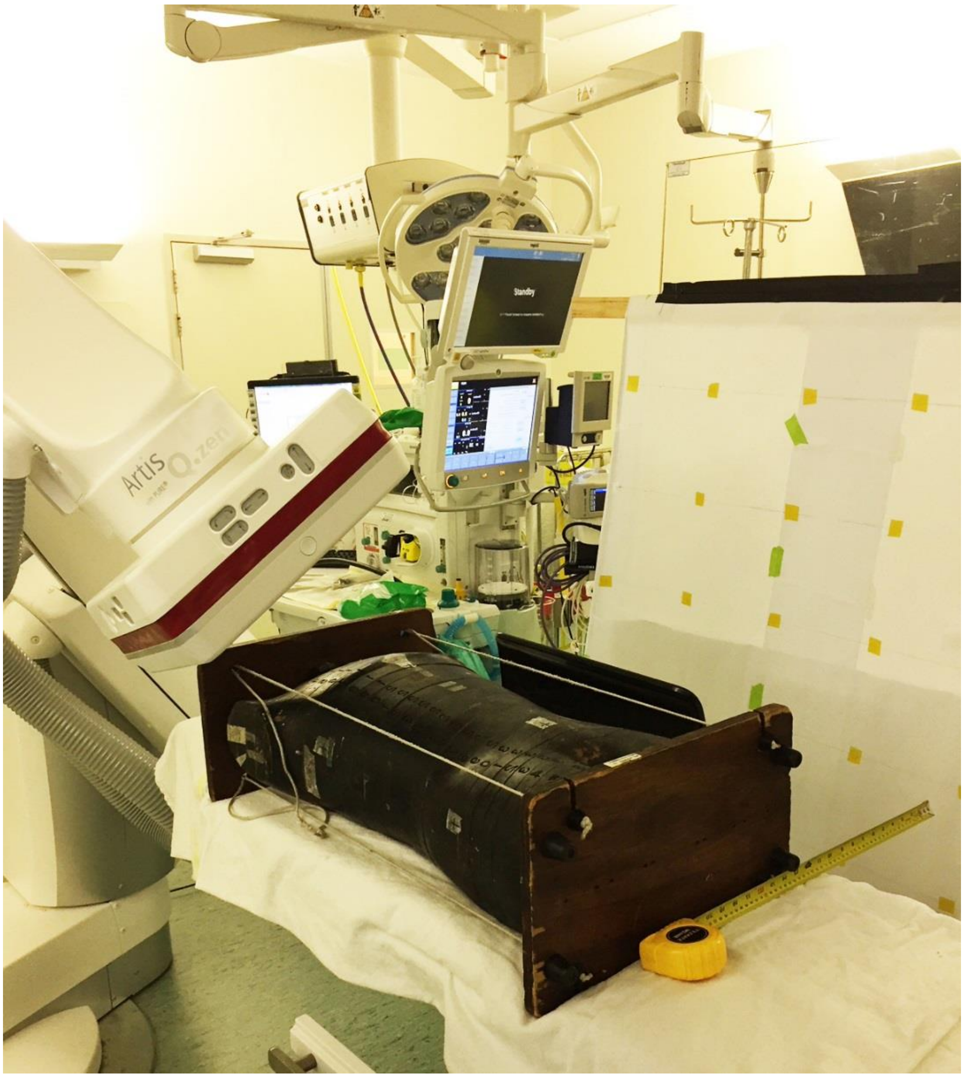

Figure 3 - Photograph of the lab setup during testing

Figure 3 above shows the set up in the lab; the shield is sitting against the far side of the phantom, and the dosimeter measurement grid is shown on the piece of paper further behind that, as labelled in table 2 below.

Table 2 - Testing grid and distances. The centre of the grid (C) aligns with the centre of the X-ray Shield

Position		A	B	C	D	E
	Distance	-40 cm	-20 cm	0 cm	20 cm	40 cm
1	50 cm					
2	70 cm					
3	90 cm					
4	110 cm					
5	130 cm					
6	150 cm					

The first test was performed with the gantry tilt 0º

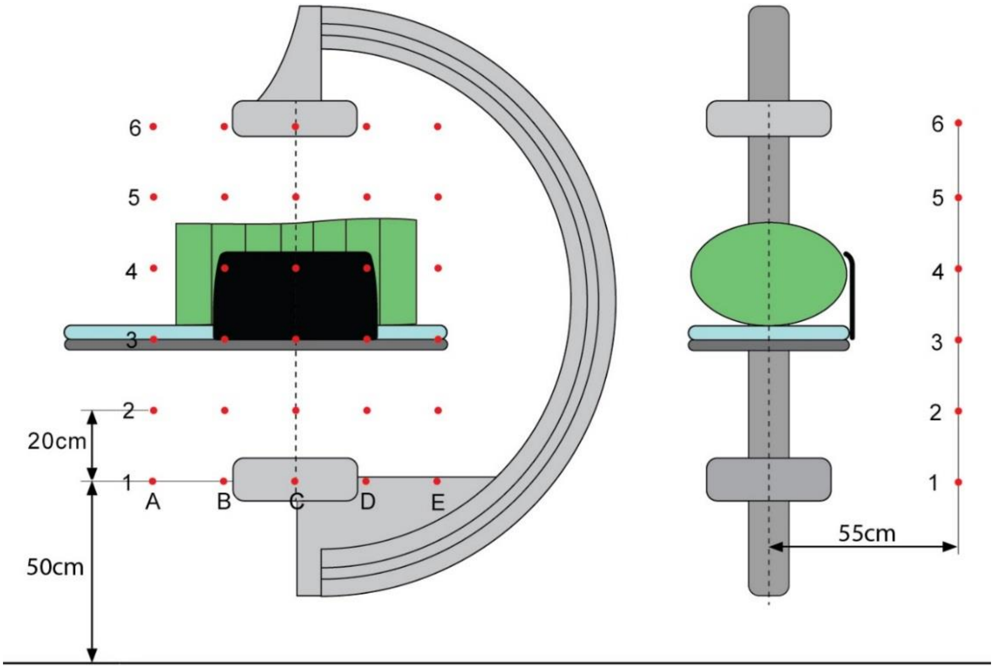

Figure 4 - Side views of the RAO 0 / CRAN 0 setup

The second test was performed with RAO 34° / CRAN 20°.

This is an extreme case of angulation, which causes a different scatter pattern off the phantom and onto the radiologist. For the two different rotations of the C-Arm, the amount of radiation is very different. This is due to properties of the beam as well as the direction of scatter. As such, the two different orientations cannot be directly compared.

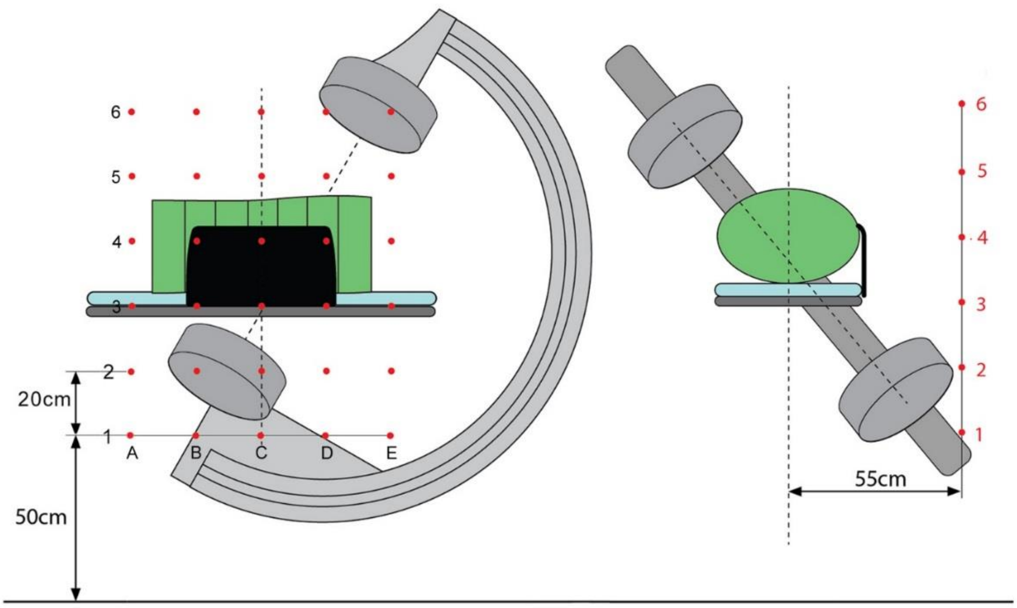

Figure 5 - Side views of the RAO 34 / CRAN 20 setup

As visible in Figures 4 and 5, in both tests the grid is positioned in the same location relative to the Operating Table.

5 Results:

Gantry Tilt 0º

Table 4 below summarises the percentage reduction for 0º gantry tilt

Table 3 - Unadjusted percentage reductions of radiation for the 0º orientation (in %)

	A	B	C	D	E
1	0.09	-1.72	-18.38	-9.18	-2.19
2	5.42	-1.53	-0.81	0.31	7.44
3	43.80	47.62	59.68	61.52	31.66
4	64.73	67.74	74.75	93.09	47.07
5	75.59	76.34	65.18	60.23	69.57
6	58.27	67.75	45.45	41.07	41.39

Note that the negative readings are not physically viable, as lead absorbs radiation and will not be a source of backscatter at the energy level of X-Rays. The negatives are likely due to incorrect readings associated with the accuracy of dosimeter placement. The former is the likely case for very negative readings, and the latter the case for small (0±10%) readings. The highly negative readings may be treated as outliers (1C), and the slightly negative readings may be treated as essentially zero attenuation (1B etc.). The small negative and positive fluctuations will most likely be caused by the accuracy in dosimeter placement, and therefore account for no attenuation increase. For this reason, the negative values have been changed to zero in Table 5.

Table 4 -Adjusted percentage reductions of radiation for the 0º (in %)

	A	B	C	D	E
1	0.09	0.00	0.00	0.00	0.00
2	5.42	0.00	0.00	0.31	7.44
3	43.80	47.62	59.68	61.52	31.66
4	64.73	67.74	74.75	93.09	47.07
5	75.59	76.34	65.18	60.23	69.57
6	58.27	67.75	45.45	41.07	41.39

The zeroed data is shown graphically in Figure 6 below, while the comparison between the shielded and unshielded measured values is shown in Figure 7.

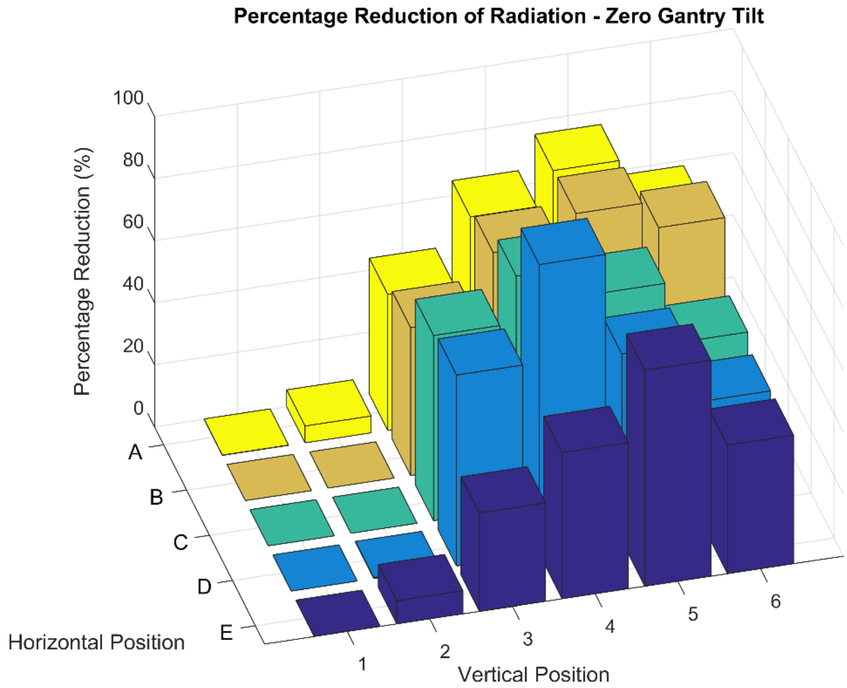

Figure 6 - 3D bar plot of the percentage reduction at zero gantry tilt

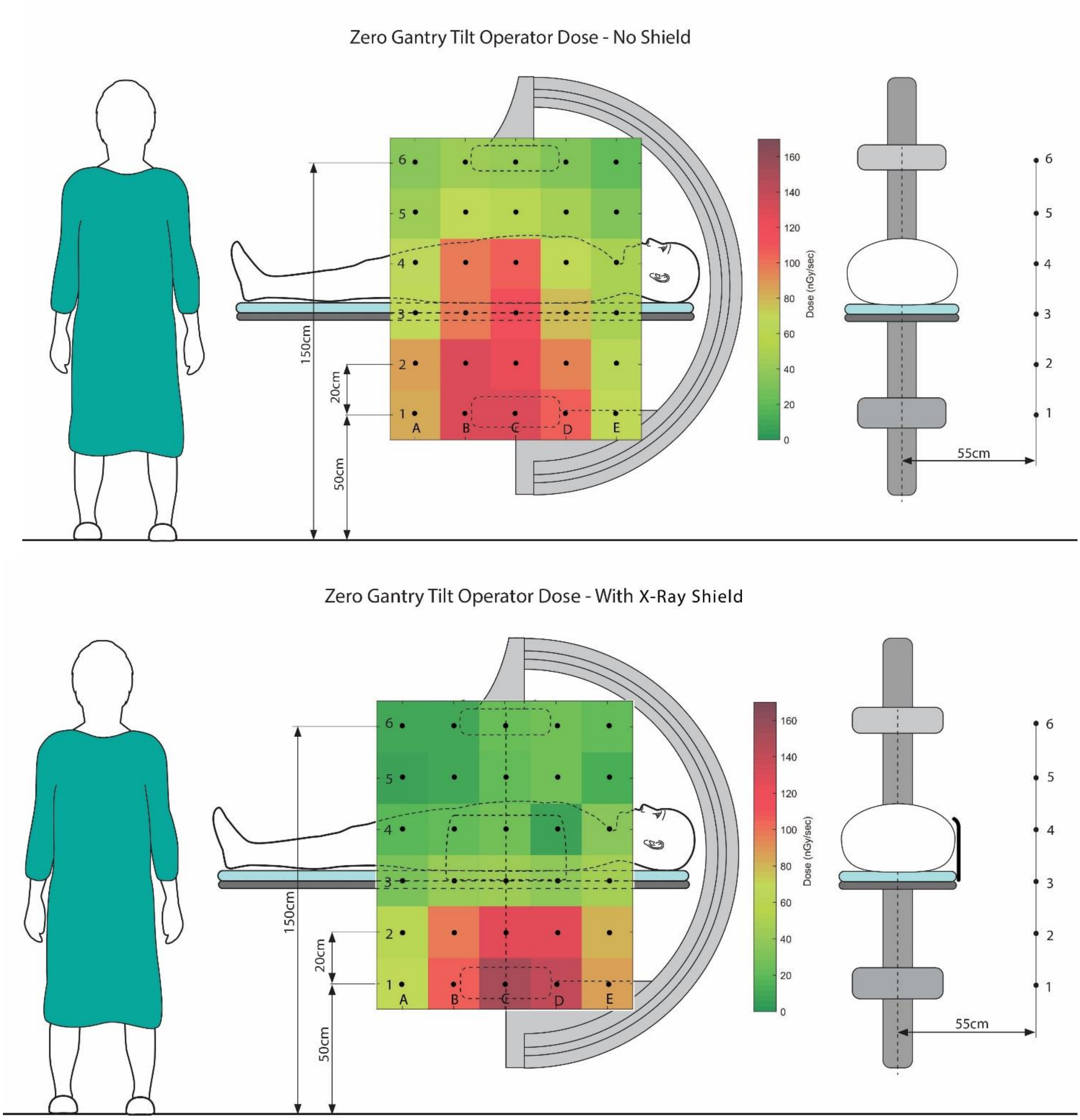

Figure 7 - Comparison of the dose to the operator with and without the X-ray Shield in place

It is evident from Figure 7 that the addition of the shield greatly reduces the dose to the operator in the region above the couch.

To further analyse the properties of the shield, the results have been condensed into averages along the vertical plane and along the horizontal plane.

It is worth noting that the very negative results in position 1 for columns C and D skew the results for the columns—as physical impossibilities, they can be reduced to 0 in the overall averaging of the horizontal average values and have been done so in the second column of values for each averaging group.

Table 5 - Horizontal and vertical average percentage reductions, with and without negative adjustment (in %).

Horizontal Position	Average Reduction	Zeroed Average Reduction
A	41.32	41.32
B	42.70	43.24
C	37.64	40.84
D	41.17	42.70
E	32.49	32.86

Vertical Position	Average Reduction	Zeroed Average Reduction
1	-6.28	0.02
2	2.17	2.64
3	48.85	48.85
4	69.48	69.48
5	69.38	69.38
6	50.79	50.79

There is little statistical difference between the results in the vertical planes. The value of E is much lower than A through D, causing a variation of 10.21% and 10.39% for the average and zeroed average, respectively. From A through D the ranges are 5.06% and 2.40%, for the average and zeroed average. Given that the shield is symmetrical, it seems unusual that position E has such great variation comparative to the other locations. In the original data, at both position 3 and 4, E is substantially lower than the averages across the rest of the positions, while the others are very similar. Retesting these two positions may be worthwhile.

The results are reasonably variable over each of the horizontal planes. The average reductions are much lower at positions 1 and 2 (50 and 70 cm), while the greatest attenuation occurs at positions 4 and 5 (110 and 130 cm). Positions 4 and 5 had almost identical attenuation averages, of 69.5% and 69.4% respectively. The overall range is very large, at 75.8% and 69.5% for the standard average and zeroed averages respectively. Given the direction of scatter and the location of the shield, it is logical that there is far less radiation protection at the level of the legs, while the highest radiation protection exists around the chest and neck.

RAO 34 / CRAN 20

Below are the results of the X-ray Shield reductions; the graphs include the raw results and the results where the negative values have been changed to zero.

Table 6 - Unadjusted percentage reductions of radiation for the RAO 34 / CRAN 20 orientation (in %)

	A	B	C	D	E
1	97.06	21.51	63.35	-7.34	8.01
2	3.36	7.42	21.12	-2.42	17.31
3	64.24	58.99	69.10	47.50	35.56
4	84.60	83.16	81.55	77.94	64.32
5	78.25	77.67	75.25	66.35	64.07
6	60.81	59.52	57.88	56.30	54.54

Table 7 - Adjusted percentage reductions of radiation for the RAO 34 / CRAN 20 orientation (in %)

	A	B	C	D	E

1	97.06	21.51	63.35	0.00	8.01
2	3.36	7.42	21.12	0.00	17.31
3	64.24	58.99	69.10	47.50	35.56
4	84.60	83.16	81.55	77.94	64.32
5	78.25	77.67	75.25	66.35	64.07
6	60.81	59.52	57.88	56.30	54.54

In this extreme angle case, there are fewer cases of negative values. Only two of the values were changed in the zeroed value case. The zeroed data is shown graphically in Figure 8 below, and a comparison between the true dose values are shown in Figure 9.

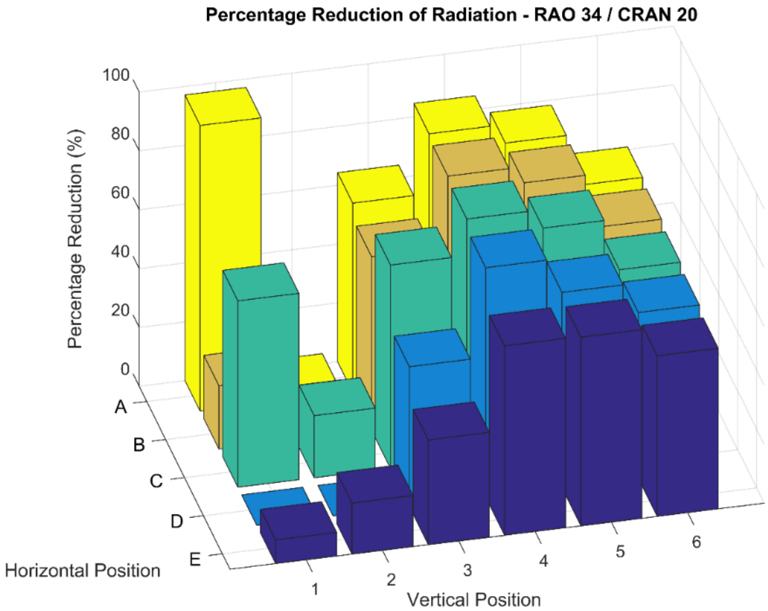

Figure 8 - 3D bar plot of the percentage reduction at RAO 34 / CRAN 20

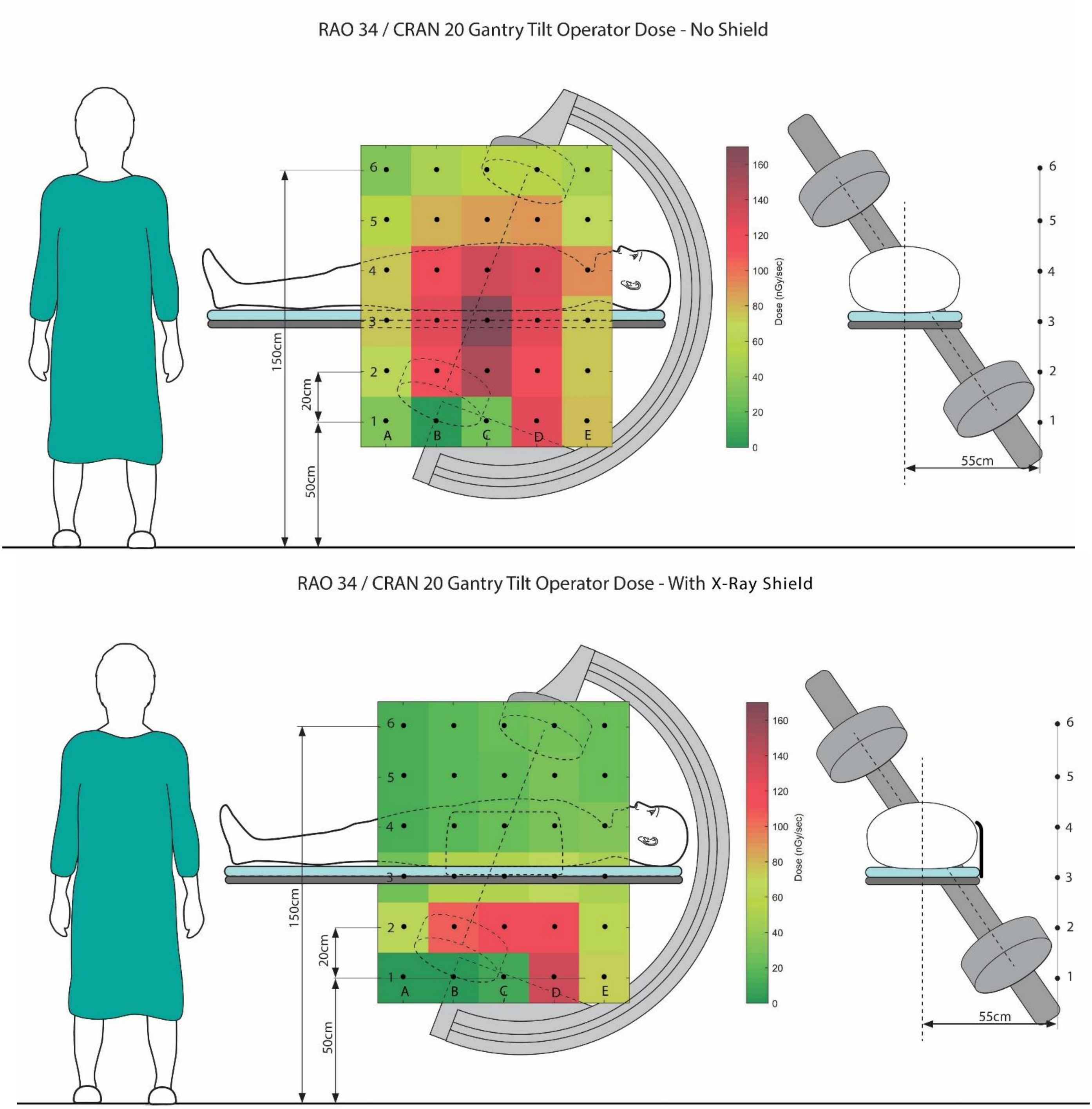

Figure 9- Comparison of the dose to the operator with and without the X-ray Shield in place

It is evident from Figure 9 that the addition of the shield greatly reduces the dose to the operator in the region above the couch.

Much like the 0º gantry position, the horizontal averages have remained in a tighter range than the row average. The ranges are 25% and 24% for the average and the zeroed average; these are much larger ranges than the experiments with 0º gantry tilt, which indicates that in this view the amount of radiation received is affected by the location of the operator in the horizontal dimension.

The vertical ranges are 69% and 68% for the average and the zeroed average scales. The averaged maximum attenuation is higher than that of the horizontal planes, and the minimum is much lower too.

Table 8 - Horizontal and vertical average percentage reductions, with and without negative adjustment

Horizontal Position	Average Reduction	Zeroed Average Reduction
A	64.72	64.72
B	51.38	51.38
C	61.37	61.37
D	39.72	41.35
E	40.63	40.63

Vertical Position	Average Reduction	Zeroed Average Reduction
1	36.52	37.99
2	9.36	9.84
3	55.08	55.08
4	78.31	78.31
5	72.32	72.32
6	57.81	57.81

Overall, the reductions in the position of extreme angulation have greater reductions in attenuation compared to those at zero / zero orientation. As is displayed in Tables 10 and 11 below, the extreme orientation sees a far higher radiation dose. The tables below display the radiation dose in the unshielded case.

Table 9 - Unleaded doses to the grid at 0º. All measurements are in nGy/sec

	A	B	C	D	E
1	70.30	104.90	128.40	128.00	84.15
2	63.60	96.20	123.70	127.70	87.09
3	50.71	76.97	111.30	97.47	68.82
4	48.66	70.25	106.00	98.10	67.62
5	31.38	47.55	60.88	70.17	44.49
6	21.21	33.61	41.61	45.31	35.49

Table 10 - Unleaded doses to the grid at RAO 34 / CRAN 20. All measurements are in nGy/sec

	A	B	C	D	E
1	171.50	12.88	143.70	666.4	410.80
2	342.50	606.20	793.10	602.8	392.90
3	403.20	669.10	878.30	666.8	401.00
4	403.20	615.10	706.10	687.2	482.40
5	313.90	425.50	463.90	473.7	359.30
6	173.30	255.20	286.30	310.3	267.90

As can be seen above, in the RAO 34/Cran 20 position there are some locations where the radiation dose is eight times that of the Gantry Tilt 0º (3C). In these cases, having high radiation attenuation properties is even more important.

6 Conclusion:

The IR Shield is proven to provide reasonable amounts of attenuation throughout both angles of the C-Arm operations, and specifically helps to reduce radiation in the extreme angled case. This shows that the IR Shield can be safely used in conjunction with other market available scatter radiation protection equipment for operators. A typical set up would also include fixed under-table shielding which would protect against much of the measured under table radiation and also the adjustable ceiling mounted shield which would provide protection from the area largely above the IR Shield. For all the tests, the beam quality was approximately 80 kVp.

At 0º

- The maximum scatter radiation reduction throughout the grid is 93%.
- At 110 cm (waist height – 4D, correlating to usual clinician position during procedure), the scatter radiation reduction with use of Adept Medical X-Ray Shield is 93%.
- At 150 cm (neck height), the maximum scatter radiation reduction with use of Adept Medical X-Ray Shield is 68%.
- At 150 cm (neck height – 6D) , the scatter radiation reduction with use of Adept Medical X-Ray Shield is 41%

At RAO 34 / CRAN 20

- The maximum attenuation throughout the grid is 85%.
- At 110 cm (waist height), the maximum scatter radiation reduction with use of Adept Medical X-Ray Shield is 85%.
- At 110 cm (waist height – 4D, correlating to usual clinician position during procedure), the scatter radiation reduction with use of Adept Medical X-Ray Shield is 78%.
- At 150 cm (neck height), the maximum scatter radiation reduction with use of Adept Medical X-Ray Shield is 61%.
- At 150 cm (neck height – 6D, correlating to usual clinician position during procedure) , the scatter radiation reduction with use of Adept Medical X-Ray Shield is 56%

There were some positions where the percentage reduction did not follow the trends of the surrounding areas. This may have been because of the irregularity of scatter causing some of the beam to move in different ways, associated with accuracy of dosimeter placement. As there were many points, the experiment did have the ability to average out any outlying values. However, it would be interesting to perform further experimentation with multiple measurements at each point, hence determining the nature of those values.

Brian Lunt
Medical Physicist
Health Physics Services Ltd

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