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Mrs. Hollingshead,

A radiation exposure reconstruction for 2016 to 2019 was requested for [redacted], an interventional radiologist who performs fluoroscopic services at Avera McKennan. The dose area product (DAP) for all interventional procedures in the interventional suite covering the four year period was provided by imaging services. In addition, the dose length product (DLP) data for interventional computed tomography (CT) procedures was also provided. The physician was not exposed to any other occupation radiation beyond these two modalities. The interventional room has a Siemens Artis Zee, and the CT scanner is General Electric LightSpeed VCT. The equipment used has not changed during this time period. A summary of this data is given in Tables 1, 2, 3 and 4.

Month	Interventional DAP (µGy•m²)	CT Interventional Procedures DLP (mGy•cm)
January	474895.6	13371.05
February	228850.3	11198.63
March	182828.1	11186.94
April	200940.6	9970.14
May	148431.2	8316.65
June	117542.5	7566.83
July	140910.3	12322.51
August	197669.3	7465.69
September	439211.4	7838.82
October	358045.7	6880.87
November	149876.0	10624.43
December	265037.1	5695.19
Total	2904238.1	112437.75

Table 1 – Summary of the 2016 fluoroscopic usage for the physician.

Month	Interventional DAP (µGy•m^2)	CT Interventional Procedures DLP (mGy•cm)
January	407281.4	11750.32
February	180234.8	15928.16
March	659844.8	13140.17
April	495839.8	14036.06
May	322227.2	13217.62
June	756406.4	18265.97
July	488675.4	15182.52
August	708056.8	11159.68
September	498987.6	20065.28
October	661290.2	21706.62
November	416084.3	18229.21
December	229666.9	14966.25
Total	5824595.6	187647.86

Table 2 – Summary of the 2017 fluoroscopic usage for the physician.

Month	Interventional DAP (µGy•m^2)	CT Interventional Procedures DLP (mGy•cm)
January	693970.3	12127.18
February	560825.6	13167.04
March	392768.5	10066.59
April	353976.9	15666.15
May	518722.9	14263.48
June	567439.5	19877.76
July	583133.8	17390.63
August	952289.7	28290.57
September	620239.7	2809.85
October	788175.2	29098.20
November	319428.3	17216.39
December	664328.1	26502.03
Total	7015298.5	206475.87

Table 3 – Summary of the 2018 fluoroscopic usage for the physician.

Month	Interventional DAP (µGy•m^2)	CT Interventional Procedures DLP (mGy•cm)
January	304725.4	26231.81
February	598464.0	18148.62
March	430033.5	19587.62
April	503225.2	17267.79
May	435586.5	18645.46
June	359887.2	21184.12
July	643813.4	25006.55
August	407038.4	22965.77
September	450172.5	11830.93
October	978264.7	21167.20
November (~Nov 20)	244277.4	15011.05
Total	5355488.2	217046.92

Table 4 – Summary of 2019 fluoroscopic usage for the physician.

A. Scatter Measurements

1. Interventional Procedures

It is expected that the amount of scatter would be most dependent upon the applied air kerma and the field size. Since DAP is simply the product of the air kerma with the field size the total scatter should be approximately proportional to the total DAP. At clinical x-ray energies, Compton scattering is the dominant interaction. Thus the scatter to DAP ratio should only be weakly dependent upon the x-ray energy as most of the energy dependence is already incorporated into the DAP measurement. In addition the scatter to DAP ratio is not expected to vary significantly between live fluoroscopy and cine loops as the prime differences are exposure rate and beam quality.

Direct measurements of scatter radiation were taken utilizing blocks of acrylic and a RaySafe X2 solid state survey meter (SN: 230047, calibrated 11/2/2018). Measurements were performed in the interventional suite with a Siemens Artis Zee system.

Exposure measurements were taken under conditions that would produce a maximal amount of scatter per DAP applied to the acrylic phantom. Measurements were taken at approximately 60 cm from the midline of the phantom both with and without the overhead protective shield. Measurements were taken at both collar and waist level with source-to-image distances (SIDs) of 90 cm and 120 cm. The waist level measurements were taken under a protective lead apron without the overhead face shield in place. The 42 cm field size was used and the focal spot to phantom distance was 65 cm. The results are shown in Table 5.

Collar Measurements

	With Shield			Without Shield		
SID	DAP (μGy•m^2)	Scatter (mR)	Scatter/DAP (mR/μGy•m^2)	DAP (μGy•m^2)	Scatter (mR)	Scatter/DAP (mR/μGy•m^2)
120	113.20	0.0082	0.00008	50.70	0.2066	0.00408
90	315.43	0.0302	0.00010	134.36	0.5475	0.00407

Waist Measurements

	With Pb Apron		
SID	DAP (μGy•m^2)	Scatter (mR)	Scatter/DAP (mR/μGy•m^2)
120	106.90	0.0082	0.000077
90	122.20	0.0071	0.000058

Table 5 – Scatter measurements from an acrylic phantom for the Siemens Artis Zee

The waist measurements with the protective lead apron demonstrate good agreement with the expected transmission through the 0.5 mm of lead. From figure C.2 of National Council on Radiation Protection and Measurements (NCRP) report 147 [1] the transmission factor is approximately 0.015 for 0.5 mm of lead and scatter radiation from peripheral angiography.

Measurements were also taken in the lateral plane with the "B" tube, but were not significantly different. Most cases are either in the single plane room or only utilize that "A" tube.

2. CT Procedures

Similar to interventional fluoroscopy, the amount of scatter from a CT procedure should be approximately proportional to the dose length product (DLP). The DLP includes both components of applied kerma and the field size, both of which strongly influence the amount of scatter. In addition, most procedures are performed with a fixed x-ray energy, 120 kVp, and beam quality.

Direct measurements of scatter radiation were taken utilizing a 32 cm body computed tomography dose index (CTDI) phantom and a RaySafe X2 solid state survey meter (SN: 230047, calibrated 11/2/2018). Measurements were performed with a General Electric LightSpeed VCT. Measurements were taken at the collar position and waist position of an individual standing next the patient and CT gantry with an adult abdomen biopsy technique. The waist measurements were taken under a protective lead apron. A majority of the CT interventional work that the physician performs are in the torso. The results are shown in Table 6.

		DLP (mGy•cm)	Scatter (mR)	Scatter/DLP (mR/mGy•cm)
Collar	Left side of gantry	82.97	6.466	0.078
	Right side of gantry	82.97	5.850	0.071
Wait	Left side of gantry	82.97	0.6230	0.0075
	Right side of gantry	82.97	0.4746	0.0057

Table 6 – Scatter from a CT scanner beside patient

The waist measurements with the lead apron demonstrate good agreement with the expected transmission through the 0.5 mm of lead. From figure A.2 of NCRP report 147 [1] the transmission factor is approximately 0.08 for 0.5 mm of lead and scatter radiation from 120 kVp CT technique.

B. Upper Bound Occupational Exposure Estimate

An upper bound estimation for the physician's occupational exposure was performed based on the data provided along with scatter measurements performed with each fluoroscopic system. The dosimeter readings are estimated from the estimated scatter exposure, in Roentgen. This is then converted to an equivalent dose, or dosimeter reading (1 mR ~ 0.876 mrem). Then the effective dose equivalent is estimated using the EDE1 estimation.

Assuming the physician doesn't utilize the overhead shield, a high estimate for the scatter to DAP ratio was taken to be 0.005 mR/µGy•m^2 for the collar badge and 0.0001 mR/µGy•m^2 for the waist badge (table 5). Applying the mR to mrem conversion and the EDE1 formula yields an effective dose equivalent of 0.00031 mR/µGy•m^2.

$$0.876\frac{mrem}{mR}\times\left(0.04\times 0.005\frac{mR}{\mu Gy\cdot m^2}+1.5\times 0.0001\frac{mR}{\mu Gy\cdot m^2}\right)=0.00031\frac{mrem}{\mu Gy\cdot m^2}$$

Applying this factor to the DAP for all 2016 to 2019 procedures yields a reasonable upper bound for the effective dose equivalent exposure obtained from interventional procedures performed in the interventional suite. It is likely that the physician was often over 50 cm from the midline of the patient during procedures, which would significantly reduce his exposure. The results for 2016 to 2019 are shown in Table 7.

Year	Total DAP (µGy•m^2)	Conversion Factor (mrem/µGy•m^2)	EDE (mrem)
2016	2904238.1	0.00031	900.3
2017	5824595.6	0.00031	1805.6
2018	7015298.5	0.00031	2174.7
2019	5355488.2	0.00031	1660.2

Table 7 – Estimated maximum exposure from the interventional suite

An upper bound estimate for the physician's exposure from the CT interventional procedures can be estimated by assuming the physician makes no effort to step away from the patient during the axial interventional scans. A high estimate for the scatter to DLP ratio would be 0.08 mR/mGy•cm for the collar badge and 0.008 mR/mGy•cm for the waist badge (table 6). Applying the mR to mrem conversion and the EDE1 formula yields an effective dose equivalent of 0.0133 mrem/mGy•cm.

$$\frac{1}{3}\times 0.876\frac{mrem}{mR}\times\left(0.04\times 0.08\frac{mR}{mGy\cdot cm}+1.5\times 0.008\frac{mR}{mGy\cdot cm}\right)=0.0045\frac{mrem}{mGy\cdot cm}$$

In addition, a sampling of cases reveals that only approximately one quarter of the DLP from each case is from the interventional series. For the pre and post interventional helical scans, the physician either steps out of the room or to the side of the gantry where exposure is negligible. The DLP to EDE factor is thus further adjusted by a conservative factor of one third, yielding 0.0045 mrem/mGy•cm. The results for 2016 to 2019 are shown in Table 8.

Year	Total DLP (mGy•cm)	Conversion Factor (mrem/mGy•cm)	EDE (mrem)
2016	112437.75	0.0045	506.0
2017	187647.86	0.0045	844.4
2018	206475.87	0.0045	929.1
2019	217046.92	0.0045	976.7

Table 8 – Estimated maximum exposure for CT interventions

Cumulating the maximum estimate from each source of occupational exposure yields a total of **1406 mrem** for 2016, **2650 mrem** for 2017, **3104 mrem** for 2018 and **2637 mrem** for 2019 (through November 20th). As this is an estimate of the maximum exposure, it is reasonable to assume that the physician's actual occupational exposure was considerably less than this value. It is highly unlikely that the actual exposure exceeded 5000 mrem.

C. Realistic Occupational Exposure Estimate

An attempt can be made to derive a more realistic estimate for the physician's occupational exposure by assuming reasonable ALARA practices. The assumptions described below were applied and validated with a different physician in the same practice who routinely wear both a collar and waist badge during procedures (see the accompanying reconstruction/correction for [redacted] for 2018). The following assumption yielded an occupational exposure estimate of 1258 mrem versus his actual dosimeter reading estimate of 1221 mrem.

A conservative estimate of 10% usage for the overhead shield is assumed. A more reasonable average distance from the midline of the patient is also assumed to be 75 cm. Observation of other interventional radiologists demonstrate a typical of distance 75 cm to 100 cm from the patient center during fluoroscopy. The inverse square law was used to estimate the scatter at 75 cm from those taken at 60 cm. The largest scatter measurements (0.0001 mR/µGy•m^2 and 0.005 mR/µGy•m^2, with and without the lead face shield respectively) were corrected for distance and shown in table 9. A composite value of the scatter per DAP for the collar dosimeter was also calculated assuming 10% usage of the overhead shield.

Scatter With Shield @ 75 cm (mR/µGy•m^2)	Scatter w/o Shield @ 75 cm (mR/µGy•m^2)	Composite Scatter @ 75 cm (mR/µGy•m^2)
0.00007	0.0033	0.0031

Table 9 – Scatter from the interventional suite.

A waist reading of 0.00007 mR/µGy•m^2 corrected for distance is 0.000047 mR/µGy•m^2 and not assumed to be reduced by the overhead lead shield. Applying the mR to mrem conversion and the EDE1 formula yields an effective dose equivalent factor of 0.00017 mrem/µGy•m^2.

$$0.876\frac{mrem}{mR} \times \left(0.04 \times 0.0031\frac{mR}{\mu Gy \cdot m^2} + 1.5 \times 0.000047\frac{mR}{\mu Gy \cdot m^2}\right) = 0.00017\frac{mrem}{\mu Gy \cdot m^2}$$

Applying this factor to the DAP for all 2016 to 2019 procedures yields a realistic estimate for the effective dose equivalent exposure obtained from interventional procedures performed in the interventional suite. The results for 2018 and 2019 are shown in Table 10.

Year	Total DAP (µGy•m^2)	Conversion Factor (mrem/µGy•m^2)	EDE (mrem)
2016	2904238.1	0.00017	493.7
2017	5824595.6	0.00017	990.2
2018	7015298.5	0.00017	1192.6
2019	5355488.2	0.00017	910.4

Table 10 – Estimated occupational exposure from interventional procedures

For the CT guided procedures, scatter to DLP ratios of 0.075 mR/mGy•cm and 0.0066 mR/mGy•cm for the collar and waist measurements were used as they were the average of the measured values. In addition, a more realistic assumption of only one quarter of the DLP coming from the interventional series was used. Applying the mR to mrem conversion, the EDE1 formula and correcting for the percentage of interventional DLP yields an effective dose equivalent of 0.0028 mrem/mGy•cm.

$$\frac{1}{4} \times 0.876 \frac{mrem}{mR} \times \left(0.04 \times 0.075 \frac{mR}{mGy \cdot cm} + 1.5 \times 0.0066 \frac{mR}{mGy \cdot cm}\right) = 0.0028 \frac{mrem}{mGy \cdot cm}$$

The results for 2016 to 2019 are shown in Table 11.

Year	Total DLP (mGy•cm)	Conversion Factor (mrem/mGy•cm)	EDE (mrem)
2016	112437.75	0.0028	314.8
2017	187647.86	0.0028	525.4
2018	206475.87	0.0028	578.1
2019	217046.92	0.0028	607.7

Table 11 – Estimate occupation exposure from CT procedures

Combining the estimated effective dose equivalent from each modality, it is estimated that the physician received approximately **809 mrem** in 2016, **1516 mrem** in 2017, **1771 mrem** in 2018 and **1518 mrem** for 2019 (through November 20th). This is below the annual maximum allowable of 5000 mrem.

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D. Conclusion

After review of all image guided procedures performed by the physician from 2016 to 2019, including those utilizing the interventional fluoroscopy suite and the CT scanner, it is estimated that the physician would likely have received an effective dose equivalent of approximately 809 mrem in 2016, 1516 mrem in 2017, 1771 mrem in 2018 and 1518 mrem in 2019 through November 20th. The estimation was derived from scatter measurements from acrylic phantoms that approximate the size of an average patient and assuming typical practices of the physician determined from staff interviews.

In addition the maximum effective dose equivalent that the physician could have received was estimated to be 1406 mrem in 2016, 2650 mrem in 2017, 3104 mrem in 2018, and 2637 mrem through November 20th of 2019. It is unlikely that the physician received this dose, but it is important to note that this value is still less than the 5000 mrem maximum allowable annual effective dose equivalent.

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References

[1] National Council on Radiation Protection and Measurement. (2004). Structural shielding design for medical X-ray imaging facilities. Bethesda, MD.

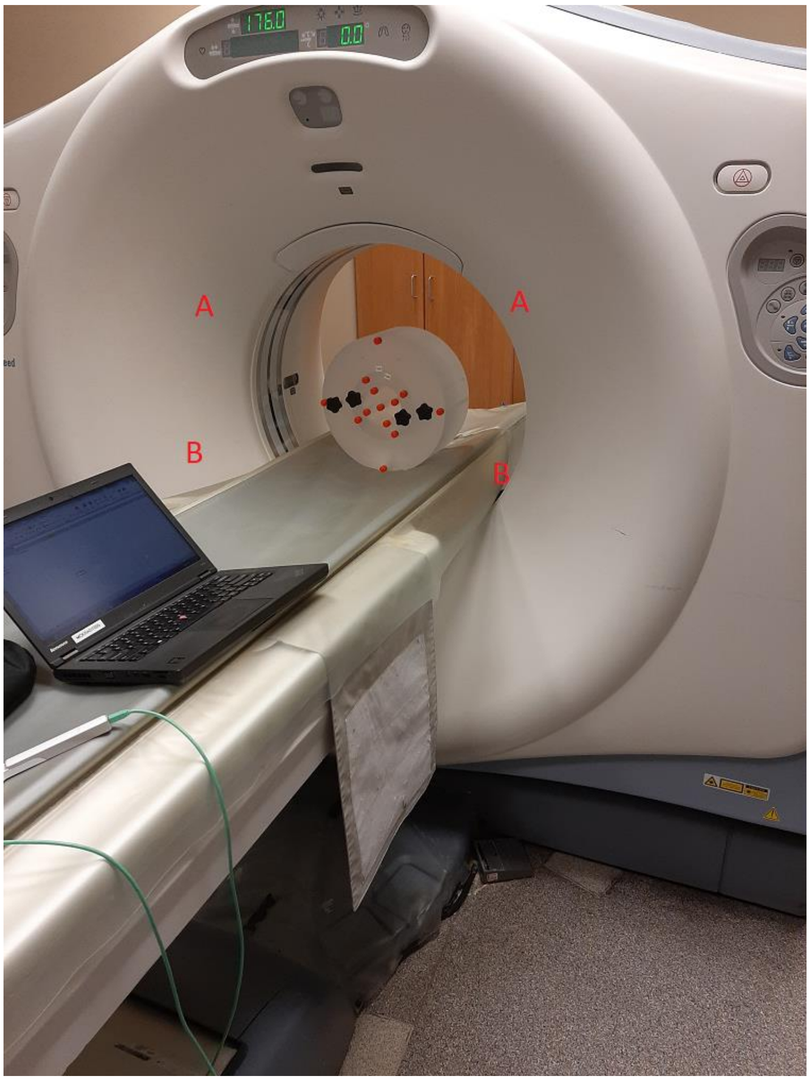
Appendix A – Scatter Measurement Set-Up

Figure 1 – Interventional Suite Scatter Measurement Set-Up
Figure 2 – CT Scanner Scatter Measurement Set-Up

A – Scatter measurements made at the collar position

B – Scatter measurements made at the waist position

Figure 1 – Scatter measurement set-up in the interventional suite



A – Scatter measurements made at the collar position

B – Scatter measurements made at the waist position

Figure 2 – Scatter measurement set-up with the CT scanner