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September 4th, 2019

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Dear Mr. Kallas,

A radiation exposure reconstruction from January 2019 to June 2019 was requested for [redacted], an interventional radiologist who performs fluoroscopic services at Avera St. Luke's. The dose area product (DAP) for all interventional procedures in the interventional suite covering the full year was provided. Additionally fluoroscopy time logs were also provided for additional procedures performed in either the general fluoroscopic room or with a C-arm. Finally, Dose length product data for interventional CT procedures was also provided. The interventional room has a Siemens Artis Zee, the fluoroscopic room has a Siemens Luminos Agile Max, the C-arm is General Electric OEC 9900 Elite and the CT scanner is General Electric LightSpeed VCT. A summary of this data is given in Table 1.

Month	Interventional DAP (μGy•m^2)	General Fluoroscopic Time (min)	C-Arm Fluoroscopic Time (min)	CT Interventional Procedures DLP (mGy•cm)
January	100043.1	6.1	15.1	1276.92
February	177513.1	7.3	33.4	1010.87
March	175886.3	9.9	0	5501.04
April	212906.6	9.0	0	2587.94
May	284261.6	7.1	27.42	3687.31
June	50784.2	7.6	10.59	0
Total	1001394.9	47	86.51	14064.08

Table 1 – Summary of 2018 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 50 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 SIDs of 90 cm and 120 cm. The 42 cm field size was used and the focal spot to phantom distance was 65 cm. The results are shown in Table 2.

Collar Measurements

	With Shield			Without Shield		
SID	DAP ($\mu Gy \cdot m^2$)	Scatter (mR)	Scatter/DAP ($mR/\mu Gy \cdot m^2$)	DAP ($\mu Gy \cdot m^2$)	Scatter (mR)	Scatter/DAP ($mR/\mu Gy \cdot m^2$)
120	270	0.0108	0.00004	59.6	0.381	0.0064
90	105.7	0.0116	0.00011	62.1	0.338	0.0054

Waist Measurements

	With Shield			Without Shield		
SID	DAP ($\mu Gy \cdot m^2$)	Scatter (mR)	Scatter/DAP ($mR/\mu Gy \cdot m^2$)	DAP ($\mu Gy \cdot m^2$)	Scatter (mR)	Scatter/DAP ($mR/\mu Gy \cdot m^2$)
120	124.4	0.0145	0.00012	63.6	0.584	0.0092
90	104.1	0.0162	0.00016	55.6	0.541	0.0097

Table 2 – Scatter measurements from an acrylic phantom for the Siemens Artis Zee

2. Fluoroscopic Procedures

As only the fluoroscopic time was available for general fluoroscopy, scatter measurements were taken with a typical clinical technique and with the maximum tube output. These can be used to estimate a 'typical' occupational exposure, and a maximum occupational exposure. The largest field size was used, as that produces the most scatter.

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 fluoroscopic room with a Siemens Luminos Agile Max. Measurements were taken at the position beside the table in-line with the x-ray tube. The Pb drapes were not equipped to provide a maximum measure of scatter. Scatter measurements with both a

clinical technique of 73 kVp, 22 mA (5 mGy/min tabletop dose rate) and a maximum technique of 111 kVp, 42 mA (46 mGy/min tabletop dose rate). The results are shown in Table 3.

Technique	Scatter Rate (mR/hr)
73 kVp, 22 mA	200
111 kVp, 42 mA	1600

Table 3 – Scatter without the Pb drape

3. C-Arm Procedures

As only the fluoroscopic time was available for C-arm procedures, scatter measurements were taken with a typical clinical technique and with the maximum tube output. These can be used to estimate a 'typical' occupational exposure, and a maximum occupational exposure. The largest field size was used, as that produces the most scatter.

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 with a General Electric OEC 9900 Elite C-arm. Measurements were taken at 50 cm from the center of the acrylic phantom. Scatter measurements with both a clinical technique of 95 kVp, 3.0 mA (15 mGy/min reference point dose rate) and a maximum technique of 120 kVp, 6.27 mA (55 mGy/min reference point dose rate). The results are shown in Table 4.

Technique	Scatter Rate (mR/hr)
95 kVp, 3.0 mA	160
120 kVp, 6.27 mA	550

Table 4 – Scatter from a C-arm at 50 cm

4. 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 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 of an individual standing next the patient and CT gantry with an adult abdomen technique. A majority of the CT interventional work that the physician performs are in the torso. The results are shown in Table 5.

	DLP (mGy•cm)	Scatter (mR)	Scatter/DLP (mR/mGy•cm)
Left side of gantry	58.72	3.377	0.058
Right side of gantry	58.72	3.013	0.051

Table 5 – Scatter from a CT scanner beside patient

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 effective dose equivalent is estimated from the estimated scatter exposure, in Roentgen. This is then convereted to an equivalent dose, or dosimeter reading (1 mR ~ 0.876 mrem). The effective dose equivalent is then estimated using Webster's formula.

Assuming the physician doesn't utilize the overhead shield, a high estimate for the scatter to DAP ratio would be 0.01 mR/µGy•m^2 (Table 2). Applying this factor to the DAP for the procedures from the first half of 2019 yields a reasonable upper bound for the collar badge 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. This is shown in Table 6.

Total DAP (µGy•m^2)	Maximal Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
1001394.9	10014	8772	2632

Table 6 – Estimated maximum exposure from the interventional suite

*EDE was estimated using Webster's formula of 0.3 * DDE.

Since only fluoroscopic time was available for procedures in the general fluoroscopic room, an upper estimate for the physician's exposure would be from the maximal scatter (1600 mR/hr, Table 3), without the Pb drape in place. This is shown in Table 7.

Total Fluoro Time (min)	Maximal Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
47.0	1253	1098	329

Table 7 – Estimated maximum exposure from the general fluoroscopic room

*EDE was estimated using Webster's formula of 0.3 * DDE.

Similarly, only fluoroscopic time was available for the C-arm procedures. An upper estimate for the physician's exposure was estimated from the maximal scatter at 50 cm (550 mR/hr, Table 4). This is shown in Table 8.

Total Fluoro Time (min)	Maximal Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
86.5	793	695	208

Table 8 – Estimated maximum exposure from C-arm procedures
*EDE was estimated using Webster's formula of 0.3 * DDE.

An upper bound estimate for the physician's exposure from the CT interventional procedures can be estimated by assuming the physician stands beside the patient for all CT scans. This includes the pre and post procedure helical scans. It is unlikely that physician would remain in the scan room for most of those scans. In addition, a majority of the DLP from each procedure is from those series and not the axial series utilized during the procedure. A slight larger value of 0.06 mR/mGy•cm scatter to DLP ratio than was measured (Table 5) was used for the estimate. This estimate is shown in Table 9.

CT DLP (mGy•cm)	Maximal Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
14064.08	844	739	222

Table 9 – Estimated maximum exposure from CT procedures
*EDE was calculated using Webster's formula of 0.3 * DDE.

Cumulating the maximum estimate from each source of occupational exposure yields a total of **3391 mrem** for the first half of 2019. 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 and more realistic patient exposures from the fluoroscopic modalities for which only time is available.

An investigation of the physician's practices in the interventional suite reveals that he does not frequently use the overhead shield. A conservative estimate of 5% 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 50 cm. The largest scatter measurements both with and without the overhead shield are corrected for distance and shown in table 10. A composite value of the scatter per DAP was also calculated assuming 5% usage.

Scatter With Shield @ 75 cm ($mR/uGy•m^2$)	Scatter w/o Shield @ 75 cm ($mR/uGy•m^2$)	Composite Scatter @ 75 cm ($mR/uGy•m^2$)
0.000071	0.0043	0.0041

Table 10 – Scatter from the interventional suite.

Using the scatter to DAP ratio of 0.0041 and estimated occupational exposure was calculated and shown in Table 11.

Total DAP ($\mu Gy•m^2$)	Maximal Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
1001394.9	4106	3597	1079

Table 11 – Estimated occupational exposure from interventional procedures
*EDE was estimated using Webster's formula of 0.3 * DDE

For a more realistic estimate of the physician's occupational exposure in the general fluoroscopic room and with the C-arm, scatter from a typical clinical technique is used. For the general fluoroscopic room, an average technique would be around 73 kVp, 22 mA at 15 pulses per second. This results in tabletop exposure rate of about 5 mGy/min. This is generally lower than most fluoroscopic systems, but typical for the Siemens system as it designed for lower exposures. The geometry for the scatter is assumed to be similar to that described in the measurement section and it is also assumed the Pb drape is not used.

For the C-arm, a typical exposure rate at the reference point is about 15 mGy/min at 95 kVp and 3.0 mA. Similar to the interventional room the physician is typically at a distance greater than the 50 cm from which the scatter was measured from the phantom. The scatter measurements were adjusted to an average distance of 75 cm from the midline of the patient. The resulting estimated occupational exposure from the general fluoroscopic room and C-arm is shown in Table 12.

	Total Fluoro Time (min)	Estimated Scatter Rate (mR/hr)	Estimated Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
General Fluoro	47.0	200	157	137	41
C-Arm	86.5	70	101	88	27

Table 12 – Estimated occupational exposure from general fluoroscopic procedures
*EDE was estimated using Webster's formula of 0.3 * DDE

For the CT guided procedures, the DLP from the pre and post procedure helical scans were ascertained from the PACS archive and removed from the total. It assumed that the physician leaves the room during these acquisition as no patient interaction is required. The same 0.06 mR/mGy•cm scatter to DLP factor was used to estimate scatter received by the physician. The result is shown in Table 13.

CT DLP (mGy•cm)	Maximal Scatter (mR)	Dosimeter Reading (mrem)	EDE* (mrem)
7825.52	470	411	123

Table 13 – Estimate occupation exposure from CT procedures
*EDE was calculated using Webster's formula of 0.3 * DDE.

The total estimated effective dose equivalent from all sources each month is shown in table 14.

Month	Interventional EDE* (mrem)	Fluoroscopy EDE* (mrem)	CT EDE* (mrem)	Total EDE* (mrem)
January	108	10	2	**120**
February	191	17	10	**218**
March	190	9	37	**236**
April	229	8	30	**267**
May	306	15	44	**365**
June	55	10	0	**65**
Total	1079	69	123	**1271**

Table 14 – The physician's estimated monthly occupational effective dose equivalent

Combining the estimated effective dose equivalent from each modality, it is estimated that the physician received approximately **1271 mrem** in for the first half of 2019. This is below the annual maximum allowable of 5000 mrem.

D. Conclusion

After review of all image guided procedures performed by the physician in the first half of 2019, including those utilizing the interventional fluoroscopy suite, the general fluoroscopy room, the mobile C-arm and the CT scanner, it is estimated that the physician would likely have received an effective dose equivalent of approximately 1271 mrem in the first half of 2019. 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. This estimation assumes that the physician rarely uses the overhead shield available in the interventional fluoroscopy suite. It is recommended that he utilize the shield more as procedures allow.

In addition the maximum effective dose equivalent that the physician could have received in 2018 was estimated to be 3391 mrem. 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, but large enough to put the physician on pace to exceed 5000 mrem for the entire year.

In addition the effective dose equivalent, the physician was estimated to have likely received approximately 4233 mrem for a lens dose equivalent (LDE) in the first half of 2019. This assumes the collar dosimeter reading estimates the LDE. In addition, the maximum he could have received was estimated to be 11304 mrem. Both of these values are below the annual maximum of 15000 mrem.

It was noted during the review that the provided data for the interventional suite indicates a large increase in fluoroscopic usage during the first half of the year. It is therefore increasingly important that the physician utilize safe radiation practices such as greater utilization of the overhead Pb shield. For example increasing its use to 50% from the estimated 5% would reduce the estimated occupational exposure for the first half of 2019 by 500 mrem.

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