Occupational Exposures During Mini C-Arm Medical Procedures

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Executive Summary

Secondary radiation (scatter and leakage) levels from mini C-arm procedures were assessed using TLDs placed for a period of three months on a mini C-arm unit in a tertiary level hospital that provides trauma services. This information was acquired to assess whether staff may require the routine use of lead protective apparel and personal dosimeters during mini C-arm procedures. Since the technique factors applied are low kVp (40-65) and low mA (20-55 μA), the main factors that determine the doses to the medical staff are actual fluoroscopic beam time (beam-on workload) and the distance of the various staff from the equipment for most of the time during procedures. The annual dose received by the operator is not likely to exceed 1 mSv, if the total beam time used by an operator is less than 15,000 seconds per year (e.g. 150 procedures at an average of 100 seconds per procedure). The wearing of radiation badge and protective apron by the operator is warranted when the operator's total beam time exceeds 15,000 seconds per year. Extrapolation from the quarterly workload data to an annual workload suggests that only 1 out of 14 operators uses a beam time greater than 15,000 seconds in a year. One way by which beam time can be optimized is for operators to take full advantage of the image-storage capabilities of the newer mini C-arms with dual monitors. Where it is difficult or impractical to keep track of an individual operator's workload, it is recommended that operators wear radiation badges and protective aprons in view of their proximity to the unit.

For the assisting staff, radiation badges and lead aprons would not be required if they generally maintain a distance of 1 meter or more to the I.I. during procedures. The scatter radiation at 1 meter from the I.I. is so low that doses to the assisting staff at this distance will not exceed 1 mSv/year even with a beam-on workload as high as 400,000 seconds per year. The doses determined in this study are consistent with the dose estimates given in Radiation Issue Note (RIN #14) published earlier by the Radiation Protection Services.

From the results of the study, the following recommendations are made:

1. Operators whose only x-ray exposure is from mini C-arm procedures, do not require personal monitoring devices or lead aprons, when their individual annual workload does not exceed 15,000 seconds of actual fluoroscopic time. One way by which beam time can be optimized is for operators to take full advantage of the image-storage capabilities of the newer mini C-arms with dual monitors. Where it is difficult to keep track of the operator's workload, it is recommended that operators use personal monitoring devices and lead aprons in view of their proximity to the mini C-arm.
2. Operators should ensure that their hands stay out of the useful x-ray beam during use.
3. Assisting staff and other persons inside the room do not require personal monitoring or protective apparel if they routinely position themselves at 1 meter or farther from the image intensifier.
4. Staff whose duties include assisting with other x-ray procedures that require the use of personal monitoring devices are advised to wear their monitors in the mini C-arm room.
5. For other persons located outside the room, no additional protection is required (i.e. no additional shielding in the walls needed).

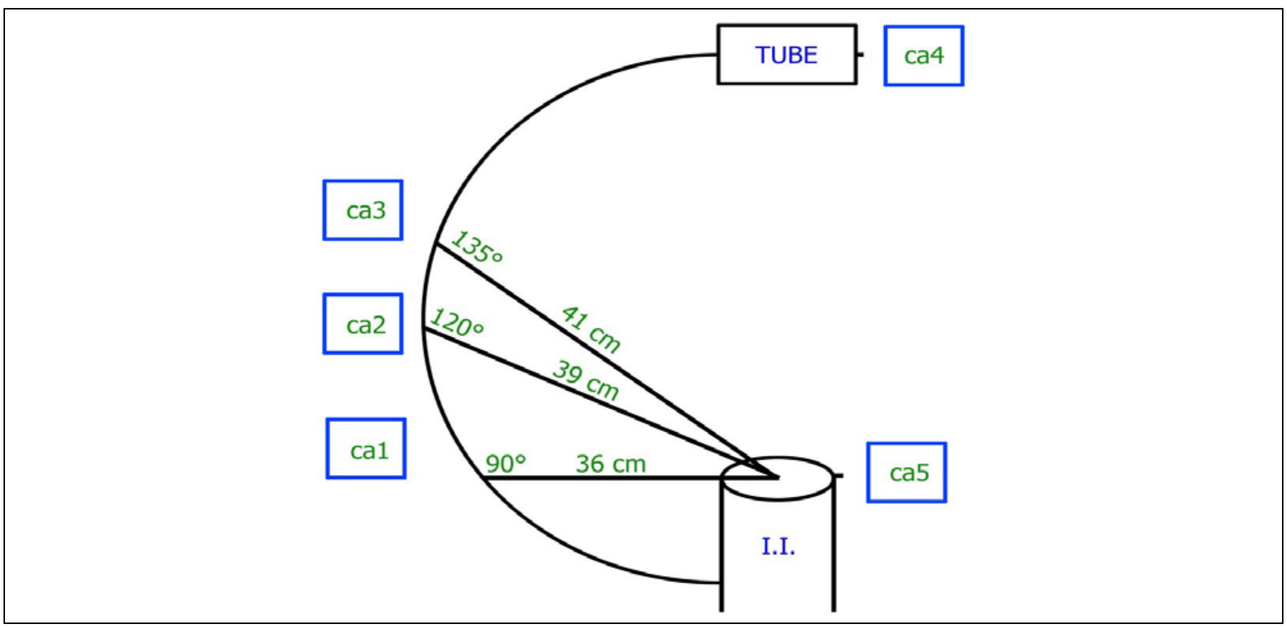
Introduction

The purpose of this report is to present the result of measurements of secondary x-ray radiation levels around a mini C-arm radioscopy unit used in orthopedic medicine in a tertiary level hospital. The results are used to estimate future doses to staff working with or being in close proximity to this unit, in order to provide guidance on the need for the wearing of protective apparel and personal monitoring for operators and assisting staff. This information is also used to verify previous guidance issued by the Radiation Protection Services (RPS), in its Radiation Issue Note (RIN) #14, regarding the expected doses, personal protection requirements and facility shielding, when mini C-arm units are in use.

Methodology

Thermoluminescent dosimeters (TLDs) in the form of lithium fluoride chips supplied by RPS were used to measure the levels of secondary radiation (scatter plus leakage) around an operational mini C-arm unit. TLD packs comprising of 5 TLDs per pack were deployed on an OEC 6600 mini C-arm at different scattering angles from the image intensifier (I.I.) for the period August 15 to November 15, 2002. The location, distance, and angle of scattering from the center of the I.I. of the TLD packs are shown in Figure 1. Three TLD packs were deployed in the locker room and one in the patients' waiting room, as control TLDs to measure background radiation. Except for 3 TLDs placed on the edge of the I.I. and 1 TLD at 135^{o}, which were lost, all of the other deployed TLDs were retrieved and returned to RPS for evaluation. Information was collected on procedures performed, technique factors selected, number of procedures and actual fluoroscopic beam time of each operator, over the three-month period.

Figure 1 - Location of the Deployed TLDs on the Mini C-arm



Data and Results

Technique Factors Commonly Used

Table 1 shows the technique factors for fluoroscopic procedures performed with the mini C-arm during the period of study. Wrist procedures are most frequent, representing 39% of the beam-on workload for one quarter. The thickness of the body parts examined with the mini C-arm requires only low kVp, ranging from 40-65 kVp. The beam current is also low, with values ranging from 20-55 μA. The source to image receptor distance (SID) is 40 cm, which is shorter than for the full-size C-arms.

Table 1 - Technique Factors Commonly Used with the Mini C-arm

Type of Procedure	Number of Procedures	Range of Beam Times (sec)	Total Beam Time (sec)	% of Quarterly Beam-on Workload	kVp	μA
Wrist	53	12.3-339.2	6785.9	38.77	45-55	30-35
Ankle	49	5.6-281.1	3500.8	20.00	55-65	35-55
Hand	24	8.5-325.5	1526.9	8.72	40-50	20-25
Elbow	18	13.3-357.9	2554.0	14.59	50-60	30-40
Forearm	11	15.6-582.5	1514.5	8.65	45-55	30-35
Tib/Fib	6	41.0-142.3	461.6	2.64	50-65	35-55
Humerus	5	19.6-368.1	592.5	3.39	55-65	35-40
Foot	5	1.7-105.6	250.8	1.43	50-55	30-35
Knee	5	8.3-112.3	237.6	1.36	60-65	45-55
Femur	1	74.6	74.6	0.43	60-65	45-55
TOTAL	**177**		**17499.2**	**100**		
RANGE		**1.7-582.5**			**40-65 kVp**	**20-55 μA**

The beam times used vary significantly, from 1.7 to 582.5 seconds (sec) per procedure. The mean beam time per procedure is 99 ± 91 sec. Among the technique factors that impact on the dose, total beam time is the primary factor that determines the annual effective dose that the medical staff will receive, given the low kV and applied current.

Fluoroscopic Beam Time

Actual beam time used for each type of procedure varied significantly (Table 1). A total of 177 procedures were performed during the period of study. For this period, which is equal to one calendar quarter in a year, the beam-on workload (total beam time used) for all operators was 17,499 sec. This data can be compared with the annual workload given in RIN #14 of 200 procedures, averaging 60 sec per procedure (or 12,000 sec). The criterion of 60 sec beam time per procedure used in RIN#14 should be reviewed since the actual beam time from this study averaged 99 sec per procedure.

Since the mini C-arm is shared by several operators, the beam-on workload for each operator during the quarter was obtained, to arrive at dose estimates based on actual practice. As shown in Table 2, the actual beam time used per procedure varies for each operator. For instance, operator #1 who performed 36 procedures used twice the beam time of operator #2 who performed 31 procedures. One way by which doses can be reduced to As Low As Reasonably Achievable (ALARA) levels is for operators to take full advantage of the image-storage capabilities of the newer mini C-arms with dual monitors.

Table 2 - Operator Workload Factors for the Quarter

Operator ID #	# of Procedures	Total Beam Time Used (sec)	% Total Quarterly Beam-on Workload
# 1	36	5006.8	28.6
# 2	31	2505.5	14.3
# 3	29	2674.5	15.3
# 4	18	2519.8	14.4
# 5	17	1529.6	8.7
# 6	15	1124.9	6.4
# 7	14	1233.0	7.0
# 8	7	429.8	2.5
# 9	3	165.8	0.9
#10	2	151.9	0.9
#11	2	28.1	0.2
#12	1	82.7	0.5
#13	1	12	0.1
#14	1	34.8	0.2
TOTAL	**177**	**17499.2**	**100%**

Estimation of Occupational Exposures of Medical Staff

Doses measured with the TLDs placed at different scattering angles and distances from the I.I. are shown in Table 3. The TLDs were positioned to provide data from which to calculate the doses that will be received by the mini C-arm operator, assisting staff and other persons, at their usual positions when performing these procedures.

Table 3 - Exposure due to secondary radiation measured by TLDs

TLD Position Code	∠ of Scattering	Distance from the Center of the I.I. (cm)	Dose (mR)
ca1	90^o	36	36 ± 5 (n= 5)*
ca2	120^o	39	43 ± 5 (n= 5)*
ca3	135^o	41	48 ± 5 (n= 4)*
ca4	~180^o (side of tube)	40	4 ± 3 (n= 5)*
ca5	Edge of I.I. (away from scatter)		19 ± 5 (n= 2)*

***n = number of TLDs**

The doses received by the operator, assisting staff and other persons during mini C-arm procedures were calculated from the TLD measurements, using the distances from the I.I. based on the usual locations of medical staff during mini C-arm procedures, as shown in Appendix 1. The measured dose from the TLDs (surface dose) overestimates the effective dose (dose to the whole-body), but can be used for practical purposes as a conservative surrogate of the effective dose.

Table 4 shows the average annual doses for a worker, obtained by extrapolating the quarterly workload of 17,499.2 sec to an annual workload of about 70,000 sec for the assisting and other staff routinely in the room. At a distance of 100 cm, the assisting staff receives a dose of about 0.16 mSv/y. Other persons at a distance of 2m would receive about a quarter of that dose (i.e. around 0.04 mSv/year). For operators, if the quarterly beam-on workload equivalent to 17499.2 sec belonged to only one operator, then the operator dose would be 3.21 mSv/y. This dose is still below the dose limit of 20 mSv/y but higher than the Workers' Compensation Board's Action Level of 1 mSv/y. Since, in actual practice this equipment was shared by several operators, the dose received by Operator #1 who has the highest beam-on workload, was calculated. If Operator #1's quarterly beam-on workload is the same for the remaining three-quarters of the year, his effective dose equivalent would be about 1 mSv/y.

Table 4 - Projected Occupational Exposures of Medical Staff

Medical Staff	Quarterly Dose (mSv/qtr)	Projected Annual Dose* (mSv/y)	Operator #1 Annual Dose (mSv/y)
Operator Dose to the head/neck region at 40 cm (135°) from the center of I.I.	0.44	1.76	0.5
Dose to the chest region at 30 cm (120°) from the center of the I.I.	0.64	2.56	0.73
Dose to the body torso at 20 cm (90°) from the center of I.I.	1.02	4.08	1.34
Dose to the thigh straddling I.I.	0.17	0.68	0.19
Effective dose equivalent (whole-body)		***3.21 mSv/y***	***1.004 mSv/y***
Assisting Staff Dose to body surface at 100 cm from center of the I.I.	0.04	0.16	
Other Persons Dose to body surface at 200 cm from center of I.I.	0.01	0.04	

***assuming same person was exposed to a total beam-on workload of 70,000 sec per year**

Doses based on the TLD measurements were compared with those in RIN #14, using an annual beam-on workload of 12,000 sec as used in RIN #14 (see Table 5).

Table 5 - Comparison of Dose Estimates from TLD Study* and from RIN #14

Medical Staff	TLD Study (mSv/y)	RIN # 14 (mSv/y)
Operator Dose to body surface at 20 cm (90°) from the center of I.I.	0.8	1
Dose to the head/thyroid surface at 40 cm (135°) from the center of I.I.	0.4	0.5
Assisting Staff Dose to body surface at 100 cm from center of I.I.	0.03	0.04
Other Persons Dose to body surface at 200 cm from center of I.I.	0.01	0.01

***based on same beam-on workload of 12,000 sec in a year**

Discussion:

In general, the doses determined in this study are consistent with the dose estimates in RIN #14, under the following technique factors: 40-60 kVp, 20-55 μA, SID of 40 cm and annual beam-on workload equivalent to 200 procedures up to 60 sec. per procedure (or 12,000 sec per year). From Table 4, it appears that the effective dose equivalent of 1 mSv/y will be exceeded if the annual beam-on workload is greater than 20,000 sec. However, to be conservative, an annual beam-on workload of 15,000 sec for the operator can be used as a criterion for determining whether mandatory wearing of personal monitoring and protective clothing will be implemented. For the assisting and other staff, their doses will not exceed 1 mSv/y if they generally position themselves at 1 meter or farther from the center of the I.I. even with the full workload of 70,000 sec per year or even up to 400,000 sec per year. Assuming an annual workload of 70,000 per year, the doses received by the assisting staff may exceed 1 mSv/y if they are required to position themselves at 40 cm or closer to the I.I.

In practice, it may be difficult to keep track of an operator's actual workload or for assisting staff to estimate a distance of 40 cm from the center of the I.I. For practical reasons therefore and in keeping with ALARA, it is recommended that operators, because of their proximity to the source of secondary radiation, should wear radiation badge and lead protective apparel during mini C-arm procedures. For assisting staff, however, these are not required so long as they routinely position themselves at about 1 meter from the center of the I.I.

Conclusions:

- The TLD measurements together with the technique factors and beam-on workload provide useful information for estimating the radiation exposure to medical staff and for identifying conditions when personal protection and monitoring are required.
- Calculations made using this data confirm the dose estimates given in RIN #14, after applying the same criteria. When an individual operator's annual beam-on workload exceeds 15,000 sec, the annual dose to the operator may exceed 1 mSv/y.
- At a distance of 1 meter from the image intensifier, the doses due to scatter and leakage are so low that doses do not exceed 1 mSv/y even with an annual beam-on workload up to 400,000 seconds.

Recommendations:

- The information given in this report can be used to determine which operators and assisting staff must wear radiation badges and protective aprons based on projected workloads and distances from the mini C-arm equipment. From the data, it appears that operators whose only x-ray exposure is from mini C-arm procedures do not require personal monitoring devices or lead aprons, when their individual annual workload does not exceed 15,000 seconds of actual fluoroscopic time. Where it is difficult to keep track of the operator's workload, it is recommended that operators use personal monitoring devices and lead aprons in view of their proximity to the mini C-arm. Assisting staff and other persons inside the room do not require personal monitoring or protective apparel if they routinely position themselves at 1 meter or farther from the image intensifier.
- Lower occupational exposures may be obtained by optimizing beam time (e.g., taking advantage of image-storage capabilities of the mini C-arm for dual monitors) and by assisting staff maintaining their distance from the I.I.

- Operators should ensure that their hands stay out of the useful x-ray beam during use.
- Staff whose duties include assisting with other x-ray procedures that require the use of personal monitoring devices are advised to wear their monitors in the mini C-arm room.
- For other persons located outside the room, no additional protection is required (i.e. no additional shielding in the walls needed).
- Monitoring of secondary radiation around newly installed mini C-Arm equipment should be considered for an initial period of three (3) months, using TLDs (thermoluminescent dosimeters) to confirm that the doses are not above expected levels.
- On the basis of information and results obtained from this study, it will be appropriate for RPS to re-word the conclusion in RIN #14 as follows:

  "Whole-body doses received by operators will not exceed 1 mSv/year provided their annual individual beam-on workload does not exceed 15,000 seconds (e.g. 150 procedures up to 100 sec or 300 procedures up to 50 sec) with typical technique factors at 40-65 kVp, 20-55μA and SID of 40 cm".

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Appendix 1: Dose Calculations

1. Exposure in units of mR

From the TLD data, the exposure at specific distances from the center of the I.I. based on the usual location of medical staff during mini C-arm procedures were calculated by applying the inverse square law:

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

where: I_1 is the exposure measured with the TLDs at distances (d_1) shown in Figure 1
I_2 is the exposure at usual distances (d_2) of the medical staff from the center of the I.I. during mini C-arm procedures.

2. Absorbed dose in units of mGy

$D = I$ mR x 0.87 mrad/mR x mGy/100 mrad

where: D is the absorbed dose in mGy
0.87 is the air kerma conversion factor from exposure (I) to absorbed dose (D); this can be taken to be a measure of the shallow dose to the skin

3. Equivalent dose (to the skin) in units of mSv

$$H_T = \sum_R w_R . D_{T,R}$$

where: H_T is the equivalent dose to the tissue T (in this case skin)
w_R is the radiation weighting factor (= 1 for X-rays)
$D_{T,R}$ absorbed dose over the tissue or organ; for simplicity, assume uniform exposure of the skin for each region of interest (neck, chest, waist, leg); the doses to the skin will differ only in various regions depending on the angle of scattering

4. Effective dose equivalent in units of mSv

Applying the method based on the recommendations of the Annual National Standards Institute (Sherbini and DeCicco 2002), the effective dose equivalent is given by:

$$H_E = 0.11\, H_{P,N}(10) + 0.38\, H_{P,CH}(10) + 0.5\, H_{P,W}(10) + 0.01\, H_{P,L}(10)$$

where: H_E is the effective dose equivalent (whole-body)
$H_{P,N}(10)$ is the personal dose equivalent from the TLD on the neck region
$H_{P,CH}(10)$ is the personal dose equivalent from the TLD on the chest region
$H_{P,W}(10)$ is the personal dose equivalent from the TLD on the waist region
$H_{P,L}(10)$ is the personal dose equivalent from the TLD on the upper leg region
And 0.11, 0.38, 0.5 and 0.01 are derived tissue weighting factors

$H_{P,T}(10)$ is defined as the dose equivalent in soft tissue at a depth of 10 mm (ICRU, 1993). Although H_T which is the surface dose is most probably higher than $H_{P,T}(10)$ due to attenuation by tissue, for conservatism it was assumed in the calculations that
$H_T = H_{P,T}(10)$