A STUDY ON THE RADIOLOGICAL SAFETY OF DUAL ENERGY X-RAY ABSORPTIOMETRY BONE MINERAL DENSITOMETRY EQUIPMENT

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BRITISH COLUMBIA

Ministry of Health Services

Radiation Protection Branch

INTRODUCTION

This medical x-ray modality started attracting attention from clinicians and patients in the early 1990s. The evaluation on Bone Mineral Densitometry (BMD) has evolved from being a "questionable" diagnostic procedure to a well-accepted clinical tool for the diagnosis and management of osteoporosis. Osteoporosis is one of the major causes leading to bone fractures. In 1993, Canada has spent 563 million dollars in healthcare funding on the treatment of fractures due to osteoporosis.

There are several different modalities for BMD, such as: Dual Energy X-ray Absorptiometry (DEXA or DXA), Quantitative Ultrasound (QUS), Radiographic Absorptiometry (RA) and Quantitative Computerized Tomography (QCT). Among these, DEXA has become the preferred modality because of its accuracy and low radiation dose. The patient's effective dose for a typical BMD examination (includes one PA lumbar spine and one proximal femur scan), is in the range of 0.5 to 4.5 microsievert (uSv) for the spine scan (Huda W and Morin RL, 1996, British Journal of Radiology, 69,422-425). The dose for a femur scan is about 1/3 of that of a spine scan, depending on the technique parameters and the type of equipment used. For example, the dose for a lateral spine scan is 2-3 times that of a PA spine scan. High definition scan would also deliver 2-3 times more in dose than a fast scan. Equipment with variable tube current for different patient sizes would provide better optimization on radiation dose.

OBJECTIVE OF THE STUDY

A significant growth in the installation of DEXA equipment, mainly in the private sector, was noticed in the year 2000. Radiation Protection Branch (RPB) has received numerous calls from facility owners and operators concerning the radiological safety of DEXA units. In view of this, RPB initiated a study on the radiation levels around DEXA equipment in January 2001, with an aim of developing some general guidelines for facility owners and operators, concerning radiation protection requirements.

BACKGROUND TO THIS STUDY

Radiation Protection Officers at RPB conducted surveys on two DEXA units in 1997. One unit was a HOLOGIC QDR-4500C with fan-shaped x-ray beam and the other a LUNAR DPX-IQ with pencil x-ray beam. Stray radiation levels were measured at the side of the scan table and at the operator console, using an ion-chamber radiation monitor. The readings recorded were either very low (maximum reading was 0.09 mR per hip scan for the Hologic unit), or undetectable as in the case of the Lunar unit. Initial recommendations on radiological safety were given to owners of these two facilities.

The objective of the present survey is to re-visit the issue using a different survey methodology, to update and augment the information obtained from previous surveys. Three DEXA units with different x-ray energies and beam geometry were chosen for the survey, to reflect a broader variety of equipment. Thermoluminescent Dosimeters (TLDs) were used to monitor the cumulative radiation exposure over a period of three months. Workload factors and examination rooms sizes were taken into consideration.

The data obtained from this study and the previous surveys will be used to produce a set of generic radiological safety guidelines applicable to all DEXA BMD facilities.

SURVEY METHODOLOGY

This study has looked into two major radiological safety concerns pertaining to the operation of DEXA units for BMD examinations:

A) For the operator –

How much occupational radiation exposure is the operator subjected to?

Is the occupational exposure within limits?

Is there any safety precautions/actions required?

B) For other personnel –

Are the walls of the examination room able to provide adequate radiation shielding for people working in the vicinity?

The dimensions of the examination room and positions of the equipment and personnel were measured. TLDs were placed at the operator's console and on the interior surface of the walls of the examination room to monitor exposure from secondary radiation. TLDs located on the walls were placed at 120 cm above floor level (approximately mid-level of a person standing). In order to accommodate the different scanning motions of the x-ray unit, the centre of the scanning table is assigned to be the arbitrary centre of the x-ray source. Since a very low level of stray radiation was anticipated, a longer monitoring period of three months was required to accumulate a measurable exposure. The number of scans done during the monitoring period was also recorded to relate the radiation exposure readings to workload, for personal exposure and shielding estimations.

INFORMATION ON THE SITES SURVEYED

Site # 1 (Situated in the Nuclear Medicine Department of a hospital)

The Equipment: It is a HOLOGIC QDR 4500W unit. The x-ray source assembly generates a narrow, tightly collimated, fan shaped beam, which alternates, at power line frequency, between 100kVp and 140kVp. The tube current for all scans is 5 mA. The beam is moderately filtered with HVLs of 5.0 mm Al and 6.5 mm Al at 100 kVp and 140 kVp respectively. The fan shaped beam is 1.0 mm thick and 65 cm wide. Signals are picked up by an array of 64 multi-channel $CdWO_4$ detectors. The scanner assembly only moves in one direction along the longitudinal axis of the scan area.

Quality Assurance: The scanning software requires the operator to run a QC scan every morning during the equipment startup, using a phantom supplied with the equipment. The data obtained should be within the upper and lower QC limits and having a coefficient of variation of not more than 0.60%. The software would deny the execution of any examination protocol if the equipment failed the QC scan. The operator also has to run a weekly step-wedge test, which is for the QC of total body scans.

Workload: The examination room is operated Monday through Friday, with 12 – 15 patients per day. Usually two scans (1 PA lumbar spine & 1 hip) are done on each patient. The exposure time for each scan (hip or lumbar spine) is about 40 seconds. During the monitoring period from January 22 to April 24, 2001, a total of 749 spine and 727 hip scans were done.

Site # 2 (Situated in a private medical imaging clinic)

The Equipment: It is NORLAND Eclipse XR-Series unit. The x-ray source is a pencil beam (size not specified in the technical manual), generated by a stationary anode x-ray tube operating at 100 kVcp with 1 mA tube current. The x-ray beam is filtered by a samarium filter (Minimum filtration is 3 mm Al equivalent, K-edge = 46.8 keV), to produce two energy peaks at 46.8 keV and 80 keV. Signals are picked up by two NaI scintillation detectors of different thickness, positioned in tandem, in pulse counting mode. The scanner assembly moves in a rectilinear mode to cover the whole scan area.

Quality Assurance: The scanning software requires the operator to run a Self-Diagnostic/Q.C. scan during the daily equipment startup, using a lumbar spine phantom and another phantom supplied by Norland. Data acquisition is not possible without passing the Q.C. scan.

Workload: Scans are done Monday through Friday and some Saturdays, with about 20-30 cases per day. Two scans (Hip & lumbar spine) are done on each patient as a routine. The exposure time is about 2.0 minutes for a hip scan and 2.2 to 2.5 minutes for a lumbar spine scan. During the monitoring period from January 23 to April 9, 2001, 1,004 patients (2008 scans) were done.

Site # 3 (Situated in the Medical Imaging Department of a hospital)

The Equipment: It is a GE PRODIGY LUNAR unit. The x-ray tube operates at 76 kVcp and a current of up to 3.0 mA controlled by the software. A slit of sizes 16.7 mm X 2.94 mm collimates the beam to a narrow fan shape, with a field size of 19.2 mm X 3.3 mm measured at the tabletop. A cerium filter is used to provide 38 keV and 62 keV dual energy peaks. The inherent filtration of the x-ray tube is more than 2.9 mm Al equivalent at 70 kV.

Quality Assurance: The operating software runs a series of self-diagnosis test every time on startup, followed by a QA scan on a calibration phantom. All tests have to be passed before performing examination. The operator also carries out a weekly QC service scan using an aluminum lumbar spine phantom immersed in a water bath.

Workload: The bone densitometry unit was just 3 months old and was only operating on a part-time basis (Alternate Thursdays & every Friday – Sunday) at the time this survey commenced. About 19 cases were done each day. Two scans (Lumbar spine & hip) are usually (95%) done on each patient. The exposure time for both lumbar spine and hip scans is 29 seconds. A total of 668 patients (about 1300 scans) were done during the monitoring period from January 25 to April 25, 2001.

SURVEY RESULTS

All the detailed survey data and TLD monitoring results are illustrated in the worksheets and floor plan diagrams, given in Appendix 1.

ANALYSIS OF SURVEY DATA

Selection of Data

Workload Factor: The conventional method used for calculating the workload of a radiology facility, in terms of mA-min per week, for radiation protection purposes is not suitable with respect to a BMD facility. The exposure time (scan time) for a BMD scan is greatly affected by the beam geometry of the DEXA equipment. A pencil beam equipment requires much more time than a wide fan beam equipment to complete a similar scan. However, while the mA-min per scan for the three different DEXA units under study are quite close in value (3.3 mA-min/scan, 2-2.5 mA-min/scan and 1.5 mA-min/scan respectively), their radiation field sizes are very different. (The beam areas are 6.5 cm^2 for the wide fan beam, 0.6 cm^2 for the narrow fan beam and unknown, probably <0.25 cm^2, for the pencil beam). Such great variation in field sizes and the tiny field area would make mathematical evaluation of their secondary radiation level (using KUX methodology) undesirable. The amount of radiation required for a specific scan, is expected to be primarily dependent on the efficiency of the equipment's detection and data acquisition system. For scanning an area of the same size using similar photon energy, the dose-area product is expected to be inversely proportional to the efficiency of the detector/data acquisition system. In this study, in order to avoid such dependency on the variables in the different equipment designs, the workload is simply expressed as the number of scans done for each facility.

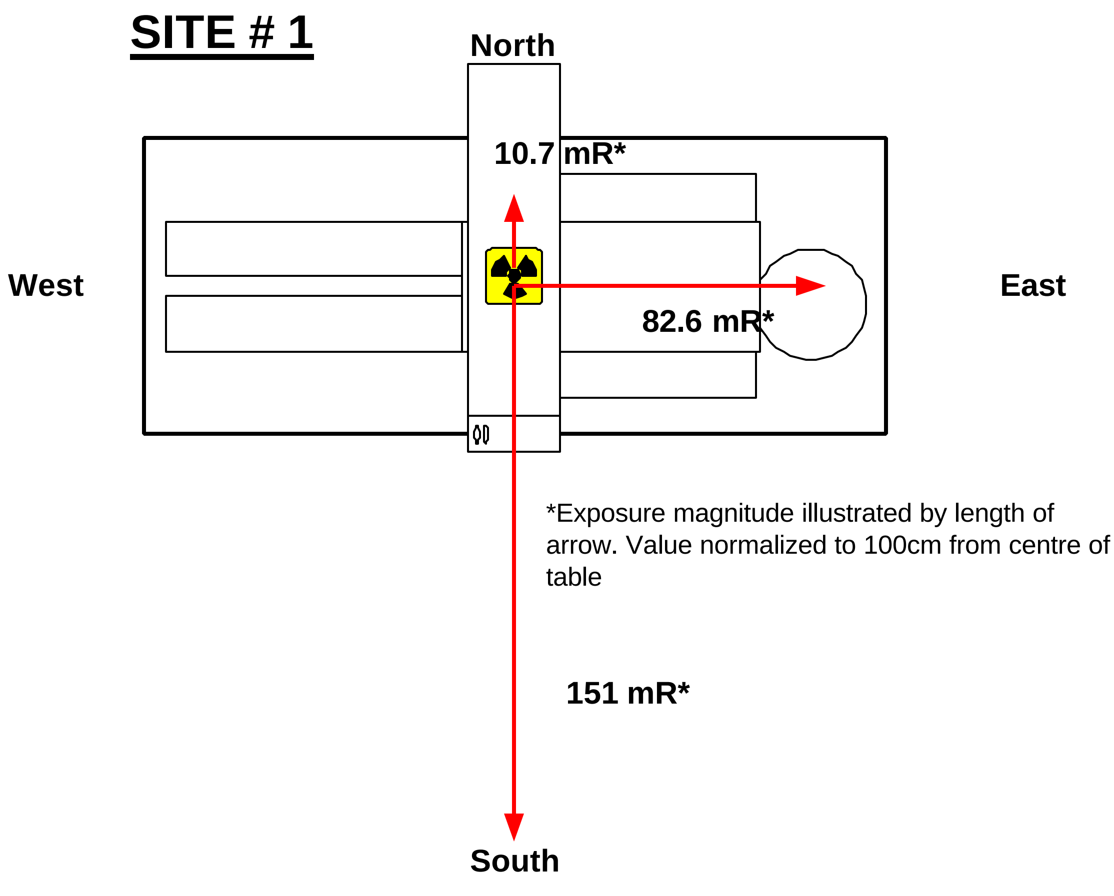
TLD Monitoring Results: Two sachets of a total of ten TLD-100 chips were placed at each monitoring location within the facility. Those sachets placed on the walls were positioned at 120 cm above floor level to measure the exposure at the mid-level of the body of personnel in standing position. Those placed at the workstations were at the level of the table to measure exposure to the body in sitting position.

The exposure readings from the ten TLD chips at each location were averaged and the exposure due to natural background (read from a set of control chips) was deducted from the average to obtain the net exposure value for each monitoring location. The standard deviation and coefficient of variation of readings from each set of TLD chips were also calculated for qualifying these results.

Generally, the TLD results presented a high coefficient of variation. This appears to be the result of a typical precision problem with TLD readers in interpreting low exposure levels (close to background). Also, one set of the TLDs placed at a workstation could have been over-shadowed by intervening objects (furniture or the operator's body) to reduce the exposure to around background reading. In order to maintain the quality of survey data, only those readings with a coefficient of variation less than 50% are accepted for evaluation. Readings from TLDs placed in the same direction from the x-ray source at different distances are also validated using the inverse square law. In all situations, the worst case scenarios are selected for radiological safety assessment.

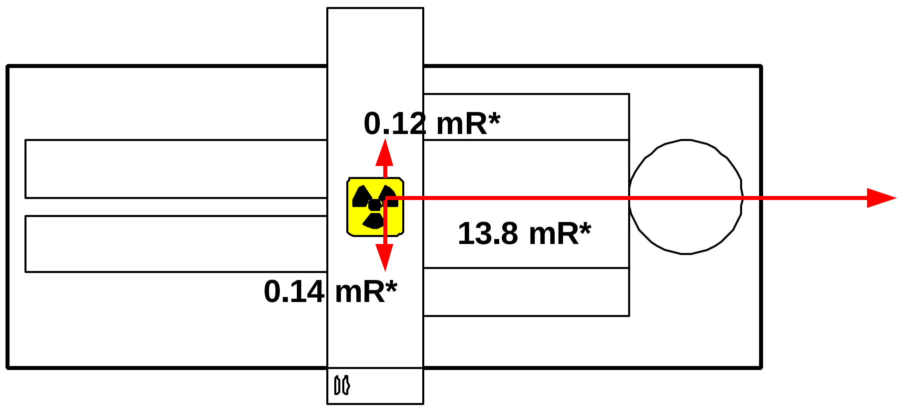
Analysis of Data

Secondary radiation levels around the scanner table: The magnitude of secondary radiation in several directions from the centre of the scanning table for each DEXA unit is illustrated in the following diagrams:



SITE # 2

North

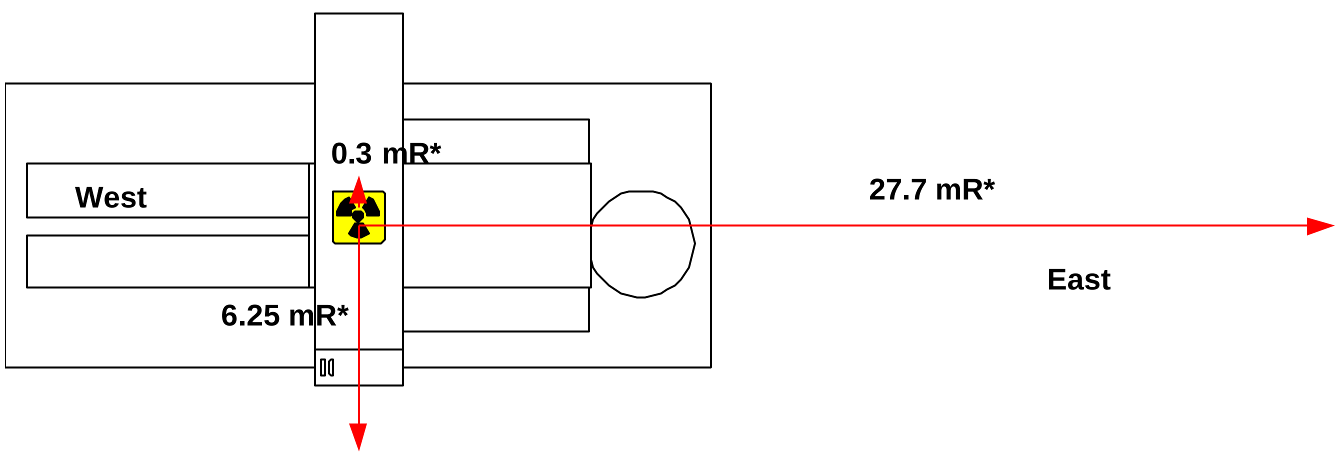


*Exposure magnitude illustrated by the length of arrow. Value normalized to 100cm from centre of table

South

SITE #3

North



*Exposure magnitude illustrated by the length of arrow. Value normalized to 100cm from centre of table

South

These diagrams indicate several common features in the secondary radiation dispersal pattern. There is a distinctively higher magnitude towards the East Side (patient's head) of the x-ray source, next to it is the south side (the operator's side). The north side is comparatively minimal because the scatter radiation is partly blocked by a vertical component of the scanner assembly. Data for the West Side has all been discounted due to high coefficient of variation, but generally the values are approximately 1/10th of those of the East Side. A possible reason is that the patient's legs are bent and elevated during lumbar spine scan, attenuating the scatter radiation from the body. This was also noted in our previous DEXA survey. (Hologic QDR-4500C unit, surveyed in June 1997.)

Secondary radiation level at the operator's workstation: A set of well-qualified exposure data is obtained at the Lion's Gate Hospital site. The TLD reading at the workstation is validated against the TLD reading on Wall B (the south side), by applying the inverse square law. When both readings are normalized to 1 meter from the x-ray source, the values are 113 mR and 151 mR respectively.

The original TLD exposure reading at the operator's workstation (180 cm from x-ray source is 34.9 mR, which is an accumulative exposure in 3 months. Assumes the workload is even throughout the year, the annual exposure will be 34.9 x 4 = 139.6 mR. This exposure, likely to be a total body exposure, when converted into effective dose will become: **139.6 ¸ 100 x 0.97 = 1.35 mSv (per year).**

This exposure would exceed the WCB Occupational Health & Safety Regulation "action level" value of 1 mSv/year.

Secondary radiation levels comparison: The most significant secondary radiation reading from each DEXA unit is chosen for comparison. Their workload factor is adjusted to a unified workload of 1,000 scans.

	Site #1	**Site #2**	**Site #3**
X-ray field size	1.0 mm x 65 cm	Pencil beam	16.7 mm x 2.94 mm
X-ray tube voltage	100/140 kVp	100 kVcp	76 kVcp
X-ray tube current	5 mA fixed	1 mA fixed	3 mA max. variable
Photon energies	100/140 kVp	46.8/80 keV	38/62 keV
Max. exposure at 100 cm East	82.6 mR	13.8 mR	27.7 mR
Workload correction factor	1000/1476	1000/2008	1000/1300
Exposure per 1,000 scans	**55.96 mR**	**6.87 mR**	**21.31 mR**

Structural shielding assessment: A worst case scenario is assessed for each site, applying the following assumptions:

1. Workload = 50 scans/day, 5 days/week, total 13,000 scans per year;
2. A standard 5/8"x2 (3.2 cm) thick gypsum drywall at 150 cm to the east side of the x-ray source;
3. Full occupancy in the adjacent room.

For site #1

The annual exposure to an occupant 2 meters away from the x-ray source without the drywall will be:

55.96 mR x 13000/1000 ¸ 2^2 = 182 mR

The Transmission (B) of 140 kVp x-ray through 3.2 cm gypsum drywall is 4.07E-01

The annual exposure to the occupant shielded by the intervening drywall will be:

182 mR x 4.07E-01 = 74 mR

The annual effective dose will be:

74 ¸ 100 x 0.97 = 0.7 mSv

For site #2

The annual exposure to an occupant 2 meters away from the x-ray source without the drywall will be:

6.87 mR x 13000/1000 ¸ 2^2 = 22 mR

The Transmission (B) of 100 kVcp x-ray through 3.2 cm gypsum drywall is 2.72E-01

The annual exposure to the occupant shielded by the intervening drywall will be:

22 mR x 2.72E-01 = 6 mR

The annual effective dose will be:

6 ¸ 100 x 0.97 = 0.06 mSv

For site #3

The annual exposure to an occupant 2 meters away from the x-ray source without the drywall will be:

21.31 mR x 13000/1000 ¸ 2^2 = 69 mR

The Transmission (B) of 76 kVcp x-ray through 3.2 cm gypsum drywall is about 1.42E-01

The annual exposure to the occupant shielded by the intervening drywall will be about:

69 mR x 1.42E-01 = 10 mR

The annual effective dose will be about:

10 ¸ 100 x 0.97 = 0.1 mSv

In all three sites, a standard gypsum drywall of 3.2 cm in thickness will be able to protect the adjacent occupant from exposing to ionizing radiation in excess of an effective dose of 1 mSv per year*, for up to 13,000 scans per year.

*The WCB Occupational Health & Safety Regulation, Part 7 Section 7.32, defines an "action level" of 1 mSv/year for the protection of workers. The International Commission on Radiological Protection (ICRP) recommended a dose limit of 1 mSv/year for the general public, in their publication. (ICRP60-1990, para. 191).

CONCLUSIONS & RECOMMENDATIONS

For the patient: The total effective dose for two routine BMD scans (Lumbar spine and hip) using DEXA technology, is only about 6 uSv. It is relatively low when compared to other radiological examinations. (e.g. Mean skin entrance dose for: Lumbar spine AP&Lat- about 6 mGy; Pelvis AP- about 4 mGy; Chest PA- about 0.15 mGy. *Documents of the NRPB Vol 10, No.1, 1999*) Through a careful selection of clinically indicated patients who would gain benefit from the examination, the practice is well justified. All three DEXA units under this study bear a software feature that would not allow examination procedure if the scanner failed the daily QC test. This is a crucial feature to ensure the precision and accuracy of the equipment, in order to optimize the diagnostic result.

For the operator: The occupational radiation exposure for the operator depends upon the type of scanner technology, the workload and the relative position of the workstation to the scanning table. For a specific DEXA unit in a typical room size, the operator's workstation is best positioned at the west side of the scanner (towards the patient's feet), keeping a distance of not less than 1 meter away from the edge of the scanning table. If the workstation has to be placed at the east or south side of the scanner, a minimum distance of 2 meters away from the edge of the table should be maintained.

It is advisable for the operator of a new facility to wear a three-monthly personnel dosimeter for an initial period of one year to assess the annual occupational dose. This monitoring arrangement is also recommended for existing facilities when a change in either the equipment type , room layout, or when there is a great increase in workload.

Unlike other radiological procedures with more dynamics, during BMD scans, the operator is usually sitting at the workstation in a regular orientation. **The operator's dosimeter should be worn at the upper body (i.e. chest) on the side facing the x-ray source.** If the dosimeter is worn on the opposite side, the secondary radiation will be attenuated by the wearer's own body, leading to under interpretation of the radiation dose. Wearing a lead protective apron is not advisable in most situations. The physical strain from wearing a lead apron all day is more detrimental than receiving the amount of radiation anticipated. If the quarterly dosimeter reading exceeds more than 0.25 mSv, consideration should be given to the provision of a transparent lead/acrylic x-ray shield, placed between the operator and the x-ray unit.

Structural shielding to protect adjacent personnel: The examination room should be an enclosed area of suitable size to maintain the minimum distance between the operator and the x-ray source. A regular radiation warning sign, same as those used for x-ray rooms, should be posted at the entrance doorway. In all circumstances, standard gypsum drywalls of 5/8" x 2 in thickness would provide adequate protection (i.e. not exceeding 1 mSv/year) for people (i.e. workers and members of the public) located in adjacent areas, for workloads up to 13,000 scans per year. Lining the walls with lead will not be necessary, unless the workload substantially exceeds this number of cases.

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Appendix 1 – Survey Results

TLD Monitoring Results

The following tables show the measured levels of secondary radiation at the locations indicated, for a period of three months at each of the three sites monitored.

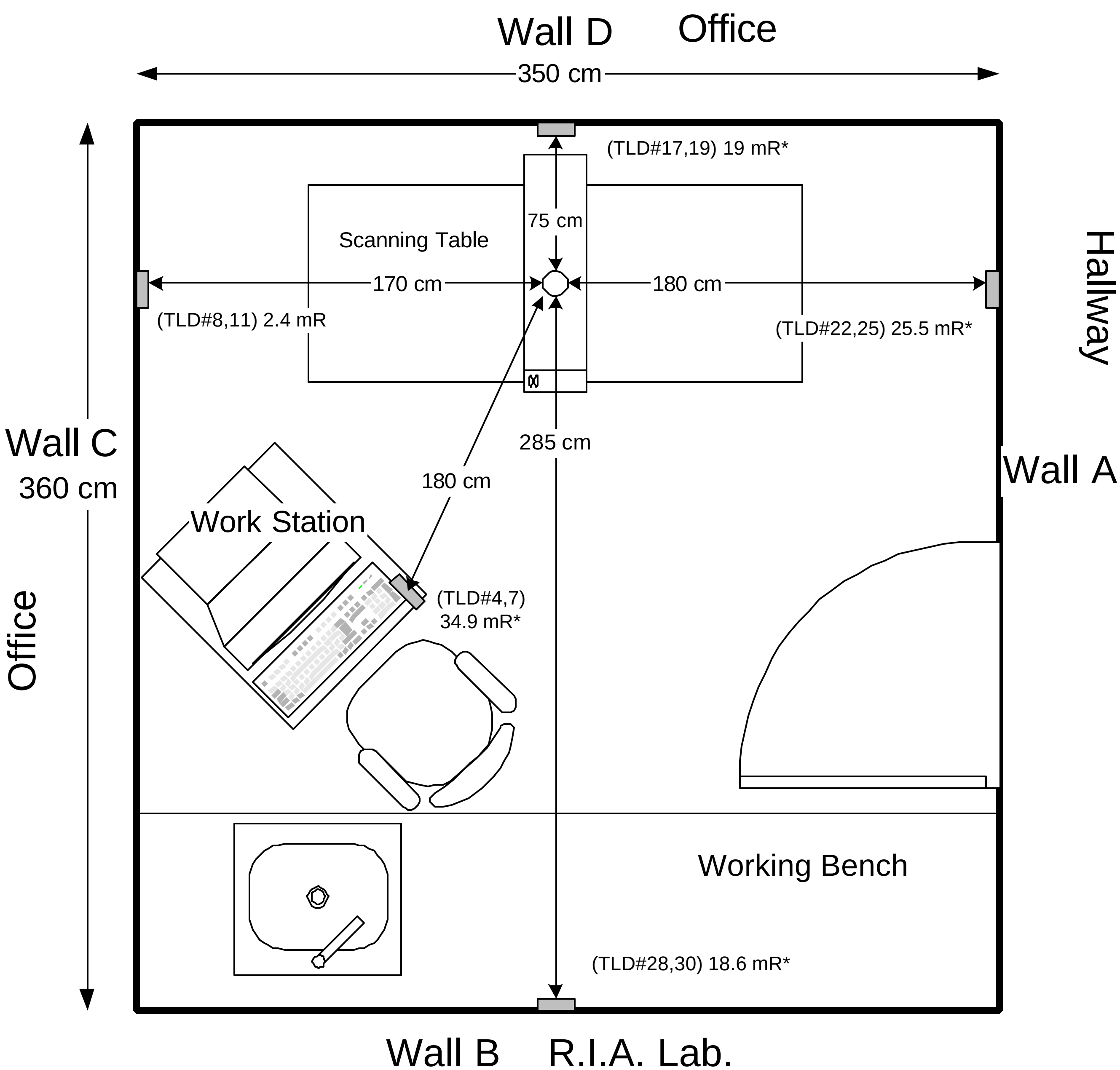
SITE # 1				
Location	**Average Exposure on TLDs (mR)**	**Standard Deviation**	**Coefficient of Variation (%)**	**Net Exposure (less background) (mR)**
Background	10.9	± 2.42	22	**0**
Wall A	36.4	± 7.24	20	**25.51**
Wall B	29.5	± 7.07	24	**18.61**
Wall C	13.3	± 7.80	59	**2.41**
Wall D	29.9	± 0.99	3	**19.01**
Workstation	45.8	± 5.29	12	**34.91**

SITE # 2				
Location	**Average Exposure on TLDs (mR)**	**Standard Deviation**	**Coefficient of Variation (%)**	**Net Exposure (less background) (mR)**
Background	8.5	± 2.80	33	**0**
Wall A	9.5	± 5.36	56	**1.00**
Wall B	8.7	± 1.77	20	**0.20**
Wall C	10.8	± 1.99	18	**2.30**
Wall D	8.5	± 3.75	44	**0.05**
Workstation	9.5	± 1.81	19	**1.05**

SITE # 3				
Location	**Average Exposure on TLDs (mR)**	**Standard Deviation**	**Coefficient of Variation (%)**	**Net Exposure (less background) (mR)**
Background	11.7	± 5.96	51	**0**
Wall A	13.2	± 6.72	51	**1.52**
Wall B	12.2	± 4.02	33	**0.50**
Wall C	14.8	± 4.84	33	**3.08**
Wall D	12.7	± 6.34	50	**1.00**
Workstation	5.4	± 3.98	74	**Non-detectable**

Floor Plan Diagrams

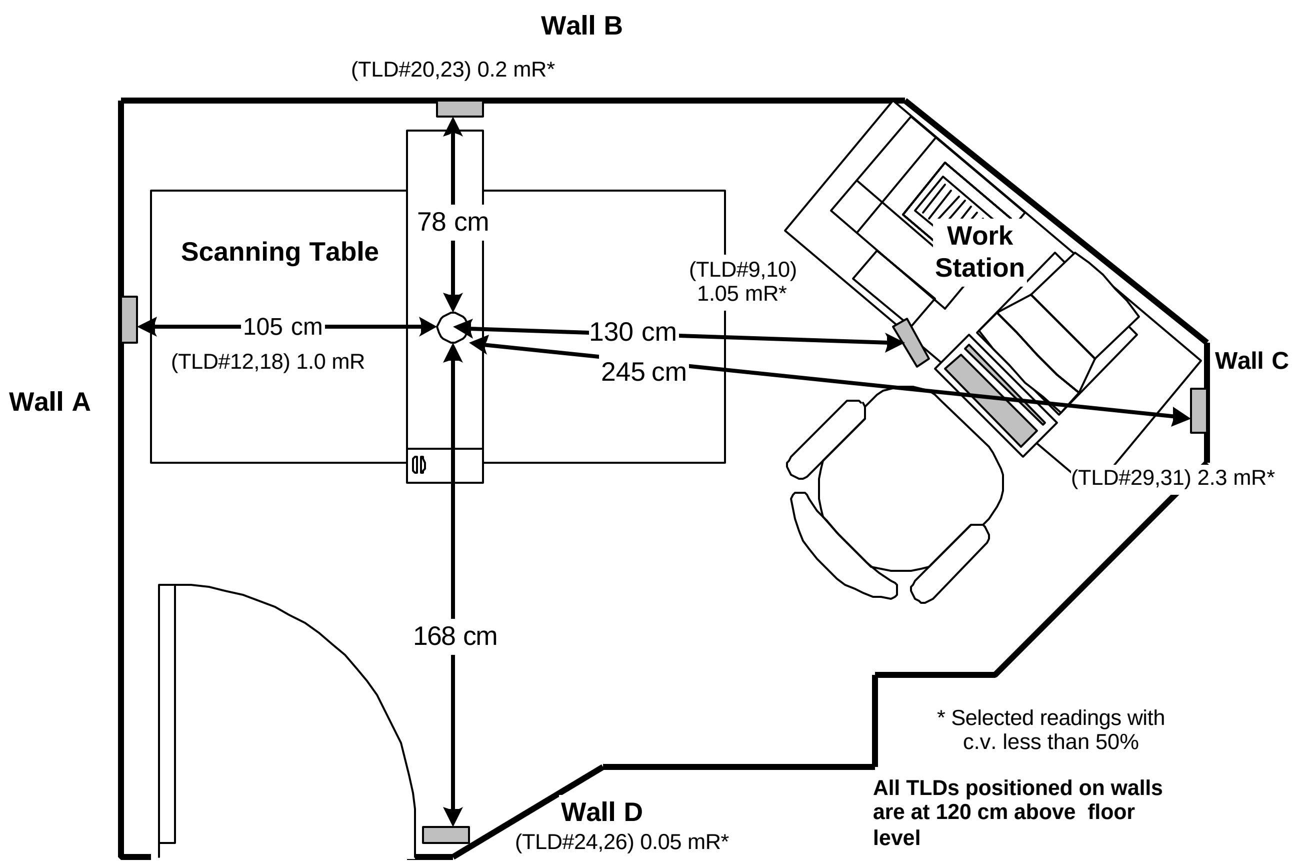
SITE # 1



* Selected readings with c.v. less than 50%

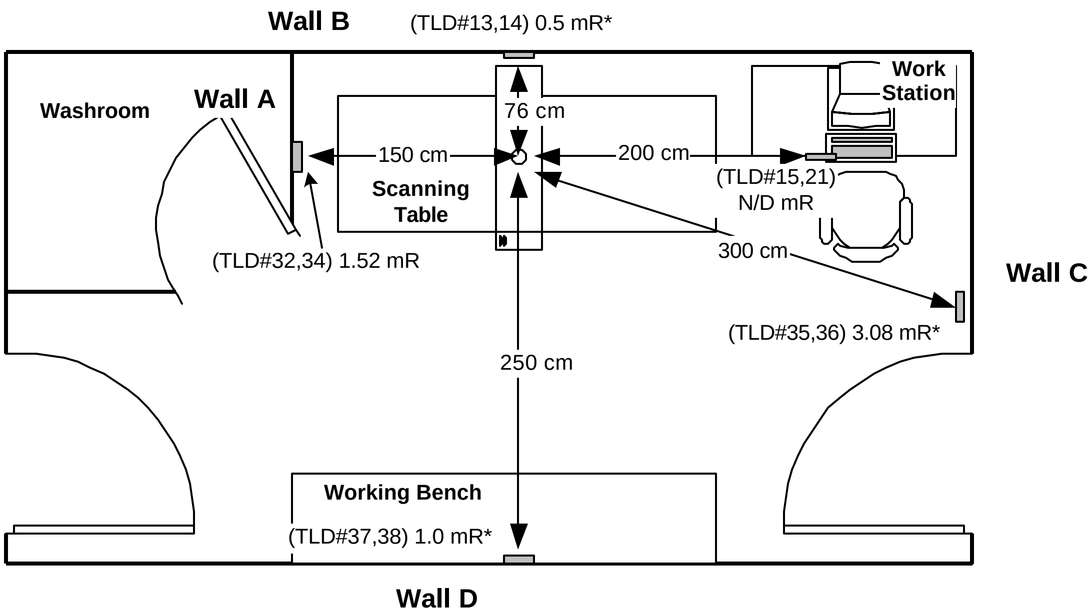
All TLDs positioned on walls are at 120 cm above floor level.

SITE # 2



Wall B
(TLD#20,23) 0.2 mR*
78 cm
Scanning Table
Work
Station
(TLD#9,10)
1.05 mR*
105 cm
130 cm
245 cm
(TLD#12,18) 1.0 mR
Wall C
Wall A
(TLD#29,31) 2.3 mR*
168 cm
* Selected readings with
c.v. less than 50%
All TLDs positioned on walls
are at 120 cm above floor
level
Wall D
(TLD#24,26) 0.05 mR*

SITE # 3



*Selected readings with c.v. less than 50%

All TLDs are positioned at 120 cm above floor