



Shielding Verification of Radiation Therapy Facilities

Melissa C. Martin, M.S. FACR, FAAPM

Therapy Physics Inc., Gardena, CA 90248 USA

melissa@therapyphysics.com

AAPM Annual Meeting August 3, 2016

Washington, D.C.

Shielding Verification Required Whenever New Machine is Installed

- **Must be performed by qualified medical physicist or health physicist**
- **Shielding verification must include**
 - Review of shielding evaluation report calculations
 - Survey measurements at occupied locations
 - Survey report documenting measurements and comparing them to shielding design goals
- **A copy of the shielding verification report must remain on file at the treatment facility**

Facility Inspection

- **Testing of safety devices**
 - Door interlock switches
 - Limit switches for beam orientation, mechanical stops, etc.
 - Beam “on/off” control mechanism
 - Opening the door causes useful beam to go to “off”
 - Closing door does not cause beam to go “on” until equipment is manually activated from the console
- **The presence of appropriate warning signs**
 - Red warning signal light when the useful beam is “on”
 - In the control area
 - Near the entrance(s)
 - Appropriate locations in the treatment room
- **Means for controlling access to vault entrance**

Warning Signs at Entrance

- X-RAY IN USE
- BEAM IN USE

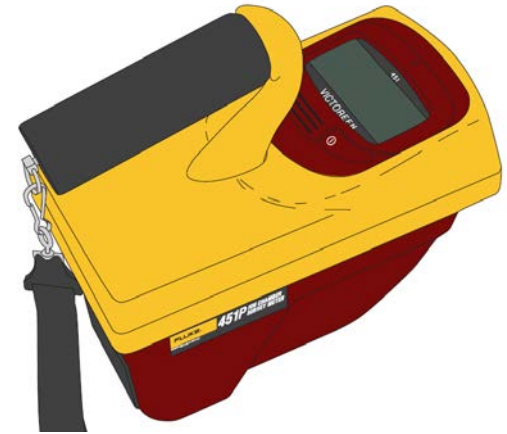


Facility Inspection (Continued)

- **Emergency off buttons**
 - On the machine console, wall of the control area, inside the treatment room and on the patient support assembly
- **Two video cameras for monitoring the patient at all times**
- **Voice intercom to establish verbal contact with the patient at all times**

Acquire Appropriate Survey X-Ray Meter

- **Survey report must include**
 - Type, model and serial number
 - Date of last calibration
 - Type and quality of radiation the instrument is designed to measure
- **Include copy of current calibration of the survey meter with report**



Neutron Survey Meter Required for Linacs > 6 MV

- Important for barriers containing metal instead of concrete
 - Particularly important at entrance
- Survey report must include
 - Type, model and serial number
 - Date of last calibration
 - Type and quality of radiation the instrument is designed to measure
- Include copy of current calibration of the survey meter with report

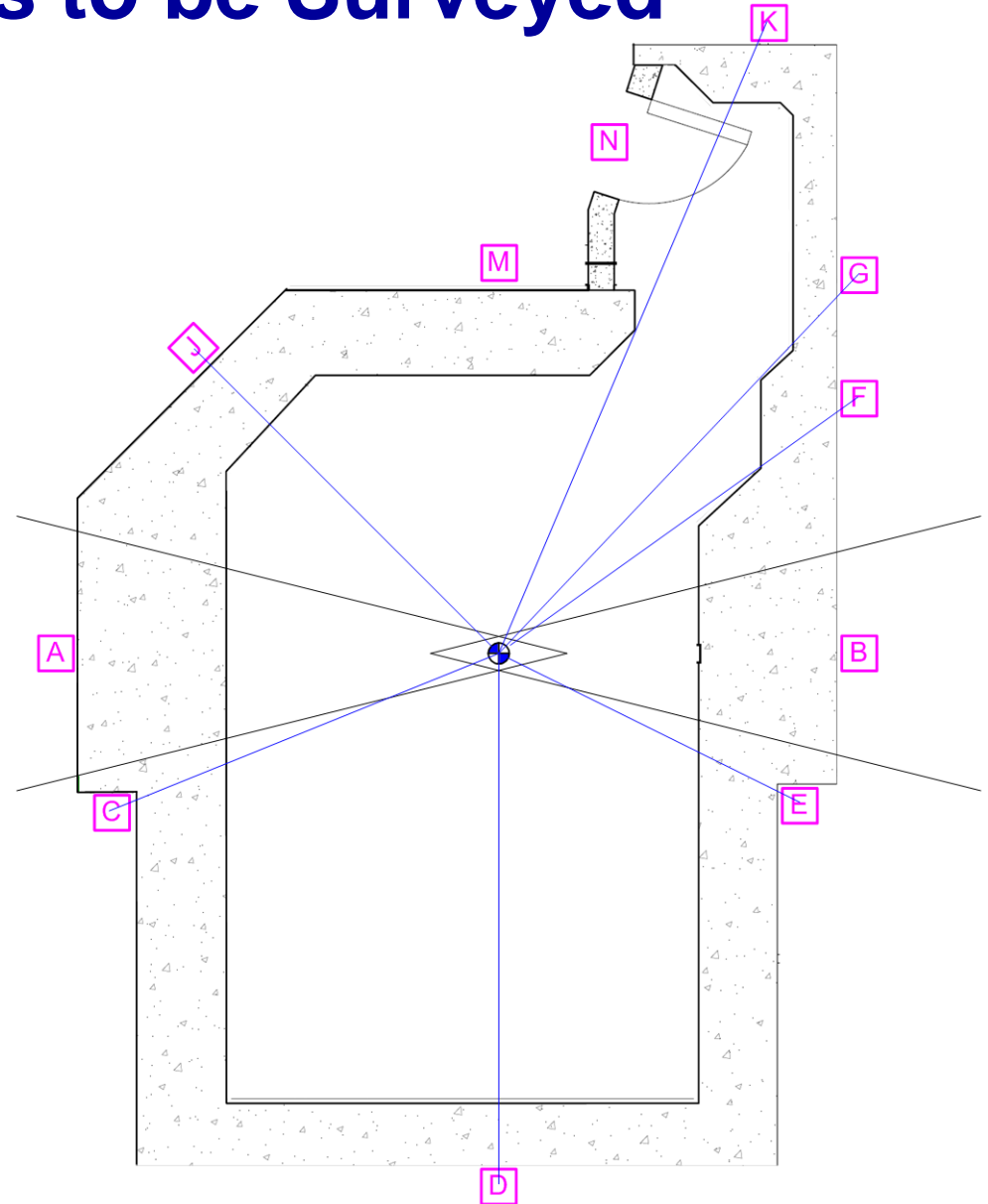


Review Shielding Evaluation Report Prior to Survey

- **Review workload and energy assumptions**
 - Ensure they are consistent with the installed equipment
- **Review occupancy assumptions and check for consistency with how space is actually used**
 - e.g., ensure store room in report is not actually an office
- **Identify locations where survey must be performed**
 - Locations with local maximum of dose rate
 - Locations with high occupancy near vault
 - Locations with relatively low margin on calculated dose rate
- **Identify any particular shielding features that should be inspected**

Survey Locations to be Surveyed

- Generally the same locations as in the shielding evaluation report
- In general, dose rate would be expected to decrease if move left or right from any selected location
- Locations A & B are primary measurements
 - No phantom at isocenter
- Phantom at isocenter for all other measurements
 - Calculations illustrated for Locations C, K, M & N



Workload Assumptions from Shielding Evaluation Report

Energy (MV)	Patients per day	Workload (Gy/pt)	Workload (Gy/wk)	MU/cGy Ratio	Leakage X-Ray	Workload (Gy/wk) Neutron	
15 3D	6	3	90	1	90	90	
15	6		90		90	90	Total
10 SBRT	1.5	10	75	3	225	225	
10 RapidArc	5	3	75	3	225	225	
10 3D	5	3	75	1	75	75	
10	11.5		225		525	525	Total
6 SBRT	2	10	100	3	300	300	
6 RapidArc	6	3	90	3	270	270	
6 3D	4	3	60	1	60	60	
6	12		250		630	NA	Total

- **Shielding evaluation report distributed workload over MV**
 - More realistic than assuming entire workload at highest MV
- **For locations with low margin, perform survey at each MV**
 - Desirable at entrance and primary barriers that have relatively low margin

At Many Locations, Measurements at Maximum MV May Be Adequate

- **Simplifies survey if only measure dose rate at maximum MV**
 - 1/3 as many measurements in this particular example
- **Entire workload assumed to be at maximum MV for survey**
 - e.g., $90 + 225 + 250 = 565$ Gy/wk workload at 15 MV
- **Survey only at maximum MV is appropriate only at locations with TADR well below shielding design goal**
 - Primary barriers with large margin on calculated dose rate
 - Secondary barriers with modest margin on calculated dose rate
 - Secondary calculations tend to be conservative
- **Review shielding evaluate report to identify locations where only single MV measurement is adequate**

Beam-On Time Calculation

- **Beam-On time per week depends on the operating dose rate at isocenter**
 - 600 cGy per minute at isocenter is typical operating dose rate
 - Record the operating dose rate in the report
- **Beam-On time per week at 15 MV operating at 600 cGy/min**
 - $90 \text{ Gy/week} / 6 \text{ Gy/min} / 60 \text{ min/hour} = 0.25 \text{ hour} / \text{week}$
- **Beam-On time at other MVs**

Line	Parameter	Units	Value			Calculation
a	Machine X-ray Energy	MV	15	10	6	
b	Operating Dose Rate	cGy /min	600	600	600	
c	Workload	Gy/wk	90	225	250	
d	Beam-On Time	hr/wk	0.250	0.625	0.694	$c / (b/100) / 60$

- **For measurements performed only at 15 MV, add the Beam-On times**
 - $\text{Total Beam-On Time} = 0.250 + 0.625 + 0.694 = 1.569 \text{ hour} / \text{week}$

Primary Barrier Shielded Dose Rate Calculation

- **Shielded dose rate calculated from survey measurement and Beam-On Time**
 - Shielded Dose Rate (mSv per week)
 - = Survey measurement (mR/hr) / 100 (mR/mSv)
 - × Use Factor × Beam-On Time (hr per week)
- **Example at 15 MV**
 - 3.7 mR/hr measured beyond primary barrier A with beam pointed at barrier
 - Negligible dose rate with beam pointed in any other direction
 - Shielded dose rate (mSv/wk)
 - = 3.7 mR/hr / 100 (mR/mSv) × 0.25 × 1.569 (hr per week)
 - = 0.0145 mSv/wk
- **Comparison with shielding design goal**
 - Location is break room (P = 0.02 mSv per week, T = 0.2)
 - Shielded dose rate must be less than P/T: 0.0145 mSv/wk < 0.1 mSv/wk
 - Alternatively, TADR = Shielded dose rate x Occupancy compared with P
 - 0.0145 mSv/wk × 0.20 (Occ. factor) = 0.0029 mSv/wk < 0.02 mSv/wk

Primary Survey Measurement Split Among 15, 10, and 6 MV

Location	MV	Gantry	Measured Exposure Rate				Shielded Dose Rate			
			X-ray (mR/hr)	Neutron (mrem/hr)	Use Factor	Beam-On (hr/wk)	X-ray (mSv/wk)	Neutron (mSv/wk)	Total (mSv/wk)	P/T
A (Break Room)	15	270	3.7	0	0.25	0.250	0.0023	0.0000	0.0023	
	10	270	1.4	0	0.25	0.625	0.0022	0.0000	0.0022	
	6	270	0.12	0	0.25	0.694	0.0002	0.0000	0.0002	
	Total	270							0.0047	0.1000 U
B (Store Room)	15	90	4	0	0.25	0.250	0.0025	0.0000	0.0025	
	10	90	1.6	0	0.25	0.625	0.0025	0.0000	0.0025	
	6	90	0.12	0	0.25	0.694	0.0002	0.0000	0.0002	
	Total	90							0.0052	0.1000 U

- Report should indicate gantry orientation for measurement
- Indicate whether location is controlled (C) or uncontrolled (U)
- Note shielded dose rate is well below the required P/T
 - Survey only at 15 MV would have been adequate

Primary Survey Only at 15 MV

Location	MV	Gantry	Measured Exposure Rate				Shielded Dose Rate				
			X-ray (mR/hr)	Neutron (mrem/hr)	Use Factor	Beam-On (hr/wk)	X-ray (mSv/wk)	Neutron (mSv/wk)	Total (mSv/wk)	P/T (mSv/wk)	
A	15	270	3.7	0	0.25	1.569	0.0145	0.0000	0.0145		
(Break Room)	Total	270							0.0145	0.1000	U
								Calculated:	0.0190		
B	15	90	4	0	0.25	1.569	0.0157	0.0000	0.0157		
(Store Room)	Total	90							0.0157	0.1000	U
								Calculated:	0.0444		

- **Shielded dose rate less than P/T with entire workload at 15 MV**
 - Actual dose rate received with clinical use will be lower
 - Mix of MVs, likely lower patient workload
 - Patient will be in place during most machine beam-on
 - Use factor 0.25 is conservative with modern 3D treatment delivery
- **Measured dose rate slightly lower than calculated in shielding evaluation report**
 - Primary measurement typically factor of ± 2 or 3 of calculated

Leakage Beam-On Time Calculation

- Based on leakage workload
- Used for secondary barrier measurements
- Leakage Beam-On time at 10 MV operating at 600 cGy/min
 - $525 \text{ Gy/week} / 6 \text{ Gy/min} / 60 \text{ min/hour} = 1.458 \text{ hour / week}$
- Leakage Beam-On time at other MVs

Line	Parameter	Units	Value			Calculation
a	Machine X-ray Energy	MV	15	10	6	
b	Operating Dose Rate	cGy /min	600	600	600	
c	Workload	Gy/wk	90	525	630	
d	Beam-On Time	hr/wk	0.250	1.458	1.750	$c / (b/100) / 60$

- For measurements performed only at highest MV, add the Leakage Beam-On times
 - Total Beam-On Time = $0.250 + 1.458 + 1.750 = 3.458 \text{ hour / week}$
 - Corresponds to $90 + 525 + 630 = 1245 \text{ Gy/wk}$ leakage workload 15 MV

Secondary Barrier Measurements Made with Phantom at Isocenter

- 6-Gallon case of water used as phantom in photo
- Stacked phantom blocks of approximately 25 x 25 x 25 cm total dimension is also common



Secondary Barrier Shielded Dose Rate

- **Shielded dose rate calculated from average survey measurement and Leakage Beam-On Time**
 - Shielded Dose Rate (mSv per week)
 - = Average survey measurement (mR/hr) / 100 (mR/mSv)
 - × Leakage Beam-On Time (hr per week)
 - Average survey measurement is average over gantry orientation
 - Simply using dose rate at gantry orientation that results in highest dose rate (instead of average) also acceptable
- **Example at 15 MV (Location K)**
 - 0.05 mR/hr measured outer maze wall
 - Shielded dose rate (mSv/wk)
 - = 0.05 mR/hr / 100 (mR/mSv) × 3.458 (hr per week) = 0.0017 mSv/wk
- **Comparison with shielding design goal**
 - Location is corridor P = 0.02 mSv per week, T = 0.2)
 - Shielded dose rate must be less than P/T: 0.0017 mSv/wk < 0.1 mSv/wk
- **Calculated dose rate (0.034 mSv/wk) is 20X higher**
 - Secondary measurement 4 to 20X less than calculated is common

Survey Measurements Near Entrance

- Neutrons are significant at 15 MV near entrance
- Data measured vs. gantry & MV

Measured X-Ray Exposure Rate (mR/hr) vs. Gantry

<i>Barrier Identification</i>		<i>0</i>	<i>90</i>	<i>180</i>	<i>270</i>	<i>Average</i>
M	15	0.5	0.35		0.35	0.400
(Control)	10	0.09	0.04		0.05	0.060
	6	0.010	0.01		0.003	0.008
N	15	0.42	0.4		0.4	0.407
(Entrance)	10	0.04	0.035		0.035	0.037
	6	0.002	0.002		0.005	0.003

Measured Neutron Exposure Rate (mrem/hr) vs. Gantry

<i>Barrier Identification</i>		<i>0</i>	<i>90</i>	<i>180</i>	<i>270</i>	<i>Average</i>
M	15	0	0		0.1	0.033
(Control)	10					
	6					
N	15	0.5	0.5		0.5	0.500
(Entrance)	10					
	6					

Shielded Dose Rate Near Entrance

Location	MV	Ave Exposure Rate			Shielded Dose Rate			P/T
		X-Ray (mR/hr)	Neutron (mrem/hr)	Leakage Beam-On (hr/wk)	Leakage (mSv/wk)	Neutron (mSv/wk)	Total (mSv/wk)	
M	15	0.400	0.033	0.250	0.0010	0.0001	0.0011	
(Control)	10	0.060		1.458	0.0009		0.0009	
	6	0.008		1.750	0.0001		0.0001	
	Total						0.0021	0.1000 C
					Calculated:		0.0051	
N	15	0.407	0.500	0.250	0.0010	0.0013	0.0023	
	10	0.037		1.458	0.0005		0.0005	
	6	0.003		1.750	0.0001		0.0001	
(Door)	Total						0.0029	0.1000 C
					Calculated:		0.0722	

- Survey at 15, 10, and 6 MV since low calculated margin
 - Note 0 neutron exposure measured at the MVs with majority of beam-on time, so measuring vs. MV has significant benefit
- Most of radiation in control area likely comes from entrance
 - Directly leakage through wall likely 4 to 20X less than calculated dose rate

Distinguishing Between Leakage and Scatter in Secondary Barrier Survey

- **Secondary radiation immediately adjacent to primary barrier is dominated by scatter**
 - Ideally should calculate scatter dose rate with Beam-On time not Leakage Beam-On time
 - Radiation will also typically vary dramatically with gantry orientation
 - Makes calculating dose rate using only the orientation with highest dose rate unduly pessimistic
- **Leakage radiation is average measurement with beam not pointing toward primary barrier adjacent to secondary barrier**
- **Scatter radiation is measured radiation with beam pointing toward adjacent primary barrier minus the leakage radiation**
- **Typically sufficient margin that this is unnecessary for shielded dose rate to be less than shielding design goal**
 - Improved assessment of radiation in high occupancy location to assure staff is primary reason to employ technique

Secondary Survey Measurements Adjacent to Primary Barrier

- By far largest dose rate with beam pointing toward barrier
- Leakage assessed with beam pointing down
- Average measured scatter =
Use Factor × (Total Measured - Leakage Measured)
 (Use factor = 0.25 typically assumed)

<i>Location</i>	<i>MV</i>	<i>Measured Exposure Rate (mR/hr) vs. Gantry</i>				<i>Average Leakage (mR/hr)</i>	<i>Average Scatter (mR/hr)</i>
		<i>0</i>	<i>90</i>	<i>180</i>	<i>270</i>		
C	15	0.02			1.2	0.020	0.2950
(Office)	10	0			0.5	0.000	0.1250
	6	0			0.1	0.000	0.0250

Secondary Shielded Dose Rate Adjacent to Primary Barrier

- Dose rate order of magnitude below 0.02 mSv/wk limit for office

Location	MV	Average Measured Exposure Rate			Scatter Leakage		Shielded Dose Rate					
		Scatter (mR/hr)	Leakage (mR/hr)	Neutron (mrem/hr)	Beam-On (hr/wk)	Beam-On (hr/wk)	Scatter (mSv/wk)	Leakage (mSv/wk)	Neutron (mSv/wk)	Total (mSv/wk)	P/T (mSv/wk)	
C	15	0.295	0.020	0	0.250	0.250	0.0007	0.0001	0.0000	0.0008		
Office	10	0.125	0.000	0	0.625	1.458	0.0008	0.0000	0.0000	0.0008		
	6	0.025	0.000	0	0.694	1.750	0.0002	0.0000	0.0000	0.0002		
Total										0.0017	0.0200	U

- If dose rate had been calculated with all workload at 15 MV and single measurement assumed to be average leakage value
 - Dose rate 2X P/T instead of 1/10 P/T
 - Important to measure vs. MV and gantry angle in this case

Location	MV	Ave Exposure Rate			Shielded Dose Rate			
		X-Ray (mR/hr)	Neutron (mrem/hr)	Leakage (hr/wk)	Leakage (mSv/wk)	Neutron (mSv/wk)	Total (mSv/wk)	P/T (mSv/wk)
C	15	1.200	0.000	3.458	0.0415	0.0000	0.0415	
Office	Total						0.0415	0.0200 U

Summary

- **Can survey all locations at all MVs and gantry orientations**
- **For many locations it is adequate to survey only at highest MV**
 - Verifies shielding with less time and staff exposure
- **For some locations, desirable to survey at all MVs**
 - Locations with low margin in shielding evaluation report
 - Vault entrance and control area
 - High occupancy locations (especially if staffed by non-radiation workers)
- **For primary barriers and back wall, surveying only at single gantry orientation is typically adequate**
 - Negligible dose rate beyond primary barrier with beam not pointed at the primary barrier
 - Measurement with beam pointing down typically adequate for back wall
- **At some locations, important to measure vs. gantry orientation**
 - Near entrance
 - Location beyond outer maze wall not protected by inner maze wall
 - Secondary barrier immediately adjacent to primary barrier

Radiation Safety Surveys in Diagnostic Radiology

- **Identify Type of Equipment: CT Scanner, Radiographic Unit, Fluoroscopic Unit**
- **Get Accurate Estimate of Planned Workload and Techniques to be used on Patients (kVp, mAs, Number of Patients per week)**
- **Get layout of the room indicating equipment location and surrounding areas so that you know the occupancy of each surrounding area.**
- **Use a phantom that simulates a patient to provide secondary scatter**

Components of Survey Report

- **Appropriate Survey Meter (Integrating or Rate Meter) with current calibration (include with survey report)**
- **Date of Survey: September 8, 2015**
- **Equipment Tested: GE R/F Room #1**
- **Location: Chapman Global Medical Center**
- **2601 East Chapman Ave.**
- **Orange, CA 92869**
- **Contact: Joe Sonntag**
- **714-633-0011 x1356**
- **Physicist: Tyler Fisher, M.S., DABR**

Components of Survey Report

- **Maximum workload assumed for this facility:**
- **Fluoroscopy: 30 patients/week, 2 minutes of fluoro time per patient**
- **Radiographic Secondary Barrier: Workload (W) = 500 mA-min per week at 100 kVp or less.**
- **Radiographic Primary Barrier: Workload (W) = 100 mA-min per week at 120 kVp or less.**
- **Measurements were performed with the system in normal, fluoroscopic mode at 83 kVp, 1.2 mA, 12" mode, Continuous Fluoro, for all secondary barrier exposures. The scattering phantom was in place for all secondary barrier measurements.**

Components of Survey Report

- All measurements were made with the scattering phantom in place at one foot from the barrier unless otherwise noted.
- Maximum Permissible Limits of Radiation Exposure are as follows:
 - General Public = 2 mR/wk
 - Occupational Workers = 100 mR/wk Maximum, 20 mR/wk Average
 -

Components of Survey Report

Location	Barrier	Occupancy	mR/hr	Effective mR/wk	Max Permis mR/wk
A) Control Window	Secondary	1.0	<0.02	<0.1	20
B) Control Wall	Secondary	1.0	<0.02	<0.1	20
C) Main Doorway	Secondary	0.125	<0.02	<0.1	2
D) Toilet	Secondary	0.05	<0.02	<0.1	2
E) Toilet Door	Secondary	0.05	<0.02	<0.1	2
F) Storage	Secondary	0.05	<0.02	<0.1	2
G) Ultrasound	Secondary	1.0	<0.02	<0.1	2
H) Nuclear Medicine	Secondary	0.5	<0.02	<0.1	2
I) Administration	Secondary	1.0	<0.02	<0.1	2
J) Open at Main Doorway*	Secondary	N/A	6.1	6.1	N/A
K) Open at Control*	Secondary	N/A	6.4	6.4	N/A

Components of Survey Report

- **Comments:** The above measurements indicate that this unit is shielded adequately for a maximum workload that will be operated on this unit.
- **Summary:** The shielding provided in the walls, doors, and windows for this room are adequate to meet all applicable California Radiation Control Regulations, Title 17 requirements.
- This shielding is adequate to keep exposure levels to personnel and the general public to below those specified in Section 30253 of the California Radiation Control Regulations (by reference Title 10 Code of Federal Regulations, Part 20).

Components of a CT Survey

- **The workload is estimated to be 10,000 mA-min per 40 hour week. Scanning parameters during the test were set at 120 kVp, 400 mA, 1 sec, 5 sets of measurements, 32 x 0.6 mm collimation (max field size). Total mAs/scan = 400 mAs x 5 scans = 2000 mAs or 33.3 mA-minutes. Total number of scans to reach 10,000 mA-min = $10,000/33.3 = 300$ scan sets.**
- **The Effective exposure in mR/wk is the calculated mR/wk multiplied by the Occupancy Factor as defined by NCRP 147. The values listed in the following table are maximum measured for each barrier.**

Components of a CT Survey

Location*	Barrier	Occupancy	mR/ 2000 mAs	Effective mR/wk	Max Permis mR/wk
A) Control Wall	Secondary	1.0	0.006	1.8	10
B) Control Window	Secondary	1.0	0.001	0.3	10
C) Scan Room Door	Secondary	0.20	0.001	0.06	2
D) Hallway	Secondary	0.20	0.002	0.12	2
E) Building Exterior 1	Secondary	0.025	0.057	0.43	2
F) Building Exterior 2	Secondary	0.025	0.018	0.14	2
G) Upstairs	Secondary	1.00	<0.001	<0.3	2

Components of a CT Survey

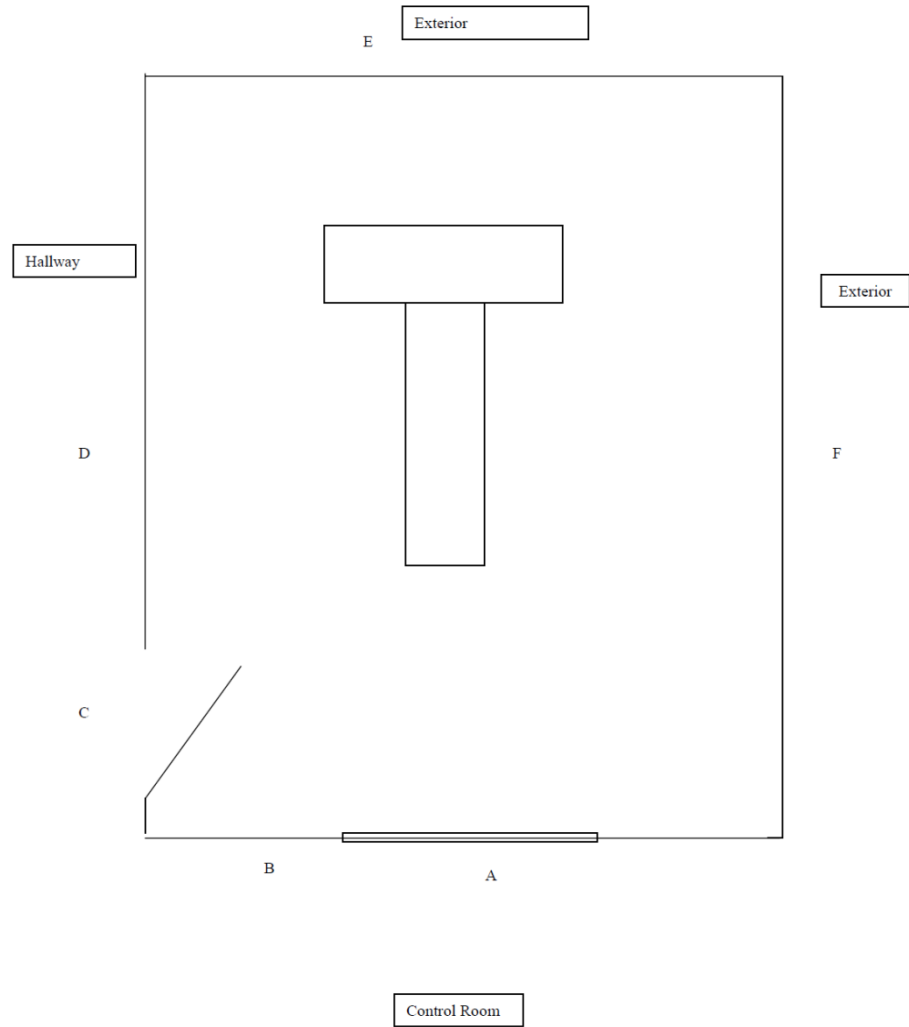
- **Comments:** The above measurements indicate that this room is shielded adequately for a maximum workload that is anticipated for use on this unit.
- **Summary:** The shielding provided in the walls, doors, and windows for this room are adequate to meet all applicable radiation control regulations of Alaska.
- This shielding is adequate to keep exposure levels to personnel and the general public to below those specified in Title 10 Code of Federal Regulations, Part 20
-

Components of a CT Survey

- **CT Surveys are always performed with the Body Phantom used for dose measurements as the phantom to simulate adult patient abdomens.**
- **Body techniques are used as this technique produces the most scatter and is worst case for safety surveys.**

Drawing for Reference Only. Not to Scale.

Drawing for CT Safety Survey



Contact Information

Melissa C. Martin, M.S., FACR, FAAPM

Certified Medical Physicist

Therapy Physics, Inc.

879 W 190th Street, Suite 400, Gardena, CA 90248 USA

Office Phone: +1 310-217-4114

Office Fax: +1 310-217-4118

Mobile Phone: +1 310-612-8127

E-mail: melissa@therapyphysics.com