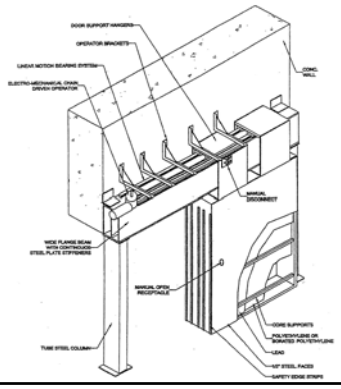
DIRECT SHIELDED DOORS
[Sliders and Swingers]

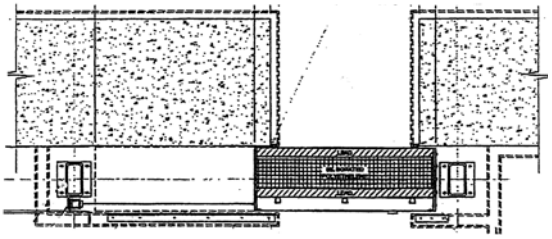
Patton H. McGinley, Ph.D.

2007 AAPM Summer School
Shielding Methods for Medical Facilities
July 29, 2007

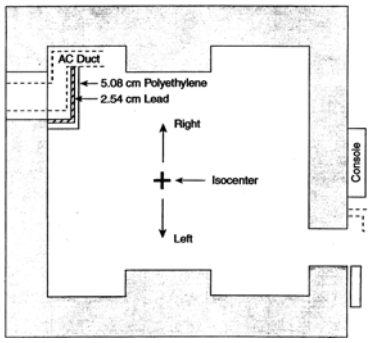
Linear Accelerator Slide Doors Isometric View



Sliding Linear Accelerator Door – Plan View



Direct Door Vault



Requirements Used for Direct-Shielded Door Example Calculations [1 of 2]

- **Equipment**
  - High energy medical accelerator with 6 and 18 MV x-ray beams
  - MV based on the British Journal of Radiology Supplement 11 data
- **Workload (W)**
  - 50,000 cGy per week of 18 MV x-ray at one meter from the target
- **Use Factor (U)**
  - ¼ for each primary wall barrier
  - ¼ for floor, and
  - ¼ for the ceiling primary barrier

Requirements Used for Direct-Shielded Door Example Calculations [2 of 2]

- **Distance from isocenter: 20 ft**
  - Measured from isocenter to the outside surface of the door
- **Room surface area (S): 2.2 x 10^6 cm^2**
- **Neutron Production**
  - 18 MV x-rays – 2.0 mrem neutron at one meter from the target per cGy of x-ray at the isocenter
  - A neutron source strength of 1.4 x 10^{10} neutrons per cGy of x-ray at the isocenter was used to calculate the capture gamma ray dose
  - 6 MV x-rays: No neutron production

Page 7

Door Calculations – Neutrons [1 of 2]

- Neutron dose equivalent (H) at the door
  - $H = H_o \ (1/d)^2$
  - Calculated using Kersey's method
- Where:
  - H = neutron dose equivalent (at the door) per unit dose of x-ray at the isocenter (mrem/cGy)
  - H_o = neutron dose equivalent at one meter from the target per cGy of x-ray (2.0 mrem/cGy)
  - d = distance in meters from the isocenter to the outside of the door (6.10 m)

Page 8

Door Calculations – Neutrons [2 of 2]

- Introducing numerical values gives:
  $H = 2.0 \ (1/6.10^2) = 0.054$ mrem n /cGy x
- Weekly dose equivalent at door position is :
  $H_{wk} = W \times H = 50{,}000 \times 0.054 = 2690$ mrem/wk
- Polyethylene 11" (27.9 cm) thick in the door
  - Polyethylene TVL 8.5 cm for head leakage neutrons
- Neutron dose equivalent outside the door
  $H_{wk} = 2690 \times 10^{-27.9/8.5} = 1.79$ mrem/wk
- Cost can be reduced by using normal polyethylene
  - 6" polyethylene (0% boron) plus 5" borated polyethylene
  - Locate polyethylene (0% boron) on room side of door

Page 9

Door Calculations – Photons Capture Gammas [1 of 2]

- Photon dose rate at door position
  $D = K \ \Phi \ 10^{-d_2 \ / \ TVL \ N}$ where $d_2 = 0$ (no maze)
  - Calculated using the method used by *Shielding Techniques for Radiation Oncology Facilities* by P.H. McGinley, Medical Physics Publishing, 2002
- Where:
  - $K = 6.9 \times 10^{-10}$ cm^2 / cGy x
  - Φ = neutron fluence (n/cm^2) at door position per cGy x-ray at isocenter
  - $d_2 = 0$ (no maze)
  - TVL N = 5.5 m

Page 10

Door Calculations – Photons Capture Gammas [2 of 2]

- Neutron fluence evaluated based on NCRP 79
  $\Phi = Q / (4 \pi d^2) + 6.66 \ Q / (2 \pi S)$
  - Where
    - Q = neutron source strength = 1.4×10^{10} n/cGy x
    - d = 6.1 m = 610 cm
    - S = surface area of treatment room = 2.2×10^6 cm^2
  - Which results in
    - Φ = 9749 n/cm^2 per cGy x
- Resulting capture gamma dose rate at the door
  - $D = 6.9 \times 10^{-10} \times 9749 = 6.72 \times 10^{-6}$ cGy / cGy x at isocenter
- Photon dose per week
  - $D_{WK} = 50{,}000 \times 6.72 \times 10^{-6} = 0.34$ cGy/wk = 340 mrem/wk

Page 11

Door Calculations – Photons Head Leakage and Patient Scatter

- Photon dose rate due to head leakage calculated based on NCRP 151
  $D_L = (1/d^2) \ (1/1000)$
  $= (1 / 6.1^2) \ (1 / 1000)$
  $= 0.000027$ cGy / cGy x at isocenter
- Weekly dose due to leakage is:
  - $D_{WK} = 50{,}000 \times 0.000027 = 1.35$ cGy/wk = 1350 mrem/wk
- Patient scatter can be ignored
  - Since scattering angle ~90°, average energy is 0.3 MV or less
  - Patient scatter energy is considerably lower than the capture gamma photons and head leakage radiation

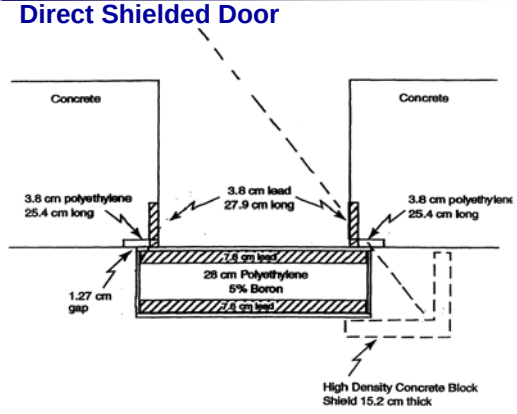
Page 12

Door Calculations – Total Photon Dose

- Total unshielded dose rate
  - $D_T = D_L + D_{WK} = 1350 + 340 = 1690$ mrem/wk
- Shielding materials in door
  - 6" (15.2 cm) lead (photon TVL 6.1 cm)
    - Capture gamma TVL (NCRP 79), head leakage TVL similar
  - 11" borated polyethylene (photon TVL 14.9")
  - 0.25" steel covers (photon TVL 4.8")
- Total 3.33 TVLs (2.49+0.74+0.10) of shielding in door
  - #TVLs lead = 15.2" / 6.1" = 2.49
  - #TVLs polyethylene = 11" / 14.9" = 0.74
  - #TVLs steel = 0.50" / 4.8" = 0.10
- Photon dose at door face: $1690 \times 10^{-3.33} = 0.79$ mrem/wk
- Photon plus neutron dose per week
  - 1.79 + 0.79 = 2.58 mrem / wk

Page 13

Direct Shielded Door



Page 14

Maximum Measured Dose Equivalent Rates for Direct Shielded Door

(N+X) Beam direction	Location	Dose equivalent rate Neutron ($nSv\ s^{-1}$)	Photon ($nSv\ s^{-1}$)	Total ($nSv\ s^{-1}$)
Down	door face	2.62	0.39	3.01
	door frame	4.75	4.73	9.48
	below HVAC	0.20	1.09	1.29
	console	0.23	0.39	0.62
Up	door face	0.85	0.69	1.54
	door frame	2.70	1.77	4.47
	below HVAC	0.20	1.09	1.29
	console	0.15	0.46	0.61
Right	door face	1.70	0.46	2.16
	door frame	5.09	2.47	7.56
	below HVAC	0.20	1.04	1.24
	console	0.54	0.39	0.93
Left	door face	0.62	3.63	4.25
	door frame	3.16	4.17	7.33
	below HVAC	0.20	3.04	3.24
	console	0.23	0.31	0.54

- Measured at sliding door, console & gonad levels below HVAC penetration
- 18 MV accelerator is operating at 6.67 cGy/s at isocenter

Page 15

Maximum Total Dose Equivalent Expected

Location	Total dose equivalent (N + X) One hour (μSv)	Seven days (μSv)	Annual (μSv)
Door face	1.27	20.6	1030
Door frame	2.84	54.1	2700
Below HVAC	0.97	13.2	660
Console	0.28	5.1	255

- Total dose equivalent for 1 hour, 1 week, and 1 year
- Calculated from dose rate based on maximum operating time anticipated for each time interval

Page 16

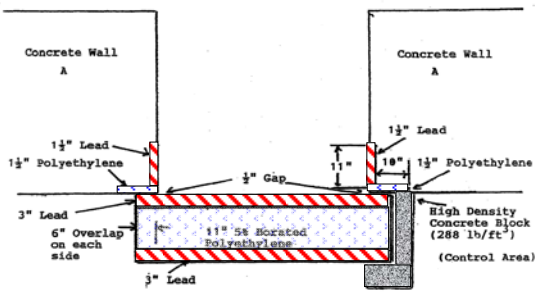
Shielding Requirements for Direct Door

- Major components of the door from inside to outside
  - 1/4" steel
  - 3" lead
  - 11" borated polyethylene (5% boron by weight)
  - 3" lead
  - 1/4" steel
- Additional Requirements
  - 1" thick steel layer covering top, sides, & bottom of door
  - Door must overlap room entrance by 6" on each side
  - Gap between door & concrete wall must be 1/2" or less
  - Gyp board should not be mounted on exterior surface of concrete in the door area
  - Lead sill is not recommended for high energy accelerator

Figure on next page illustrates these shielding requirements

Page 17

Shielding Requirements for Direct Door



Lead and polyethylene (5% boron) strips are located in both sides of the room entrance

Page 18

Field Inspection of Sliding Door [1 of 2]

1. Measure door gaps from inside & outside the room with the door closed
2. Measure distance from bottom of door to the floor
3. Determine the door overlap on sides and top
4. Check that dry wall has not been installed on concrete wall at the door
5. Make sure concrete at the door is plum vertical within 1/8"
6. Measure the dimensions of the polyethylene and lead strips

Door installation inspection must be performed before the finishing materials are in place

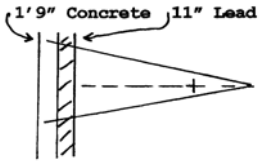
Field Inspection of Sliding Door [2 of 2]

7. Check that the polyethylene and lead strips have not been recessed too far into the concrete wall
8. Determine thickness of lead and polyethylene strips
   - Pure polyethylene is shiny white
   - 5% boron polyethylene is slightly coffee colored
9. Make sure the manual door opener is operating properly
10. Check that the anti-collision device is operating properly
11. Check motion detectors (if used)

10 MeV Accelerators and Neutrons

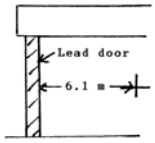
- Physicists often ignore neutrons for 10 MeV linacs
  - Due to small cross section for photoneutrons
- Neutrons can be significant at 10 MeV in some cases
  - Primary barriers that contain lead
  - Direct shielded lead doors
  - Rooms with short mazes
- Three specific examples on following charts

10 MeV Accelerators and Neutrons Example 1: Primary Barriers



- 1.5 mrem/hr neutron dose rate outside the barrier
  - Accelerator operating at 500 cGy/min at isocenter

10 MeV Accelerators and Neutrons Example 2: Direct Shielded Lead Door



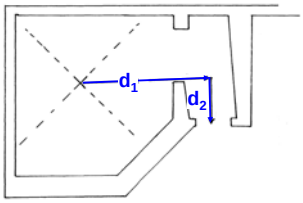
E_{avg} = 0.70 MeV "raw" neutrons

E_{avg} = 0.35 MeV after passing through head

H_o = 0.02 mrem n/cGy x

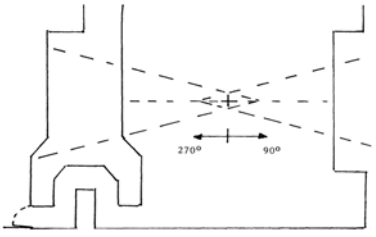
- Neutron dose rate at door = $(1/d)^2$ H_o 500 cGy/min
  - = $(1 / 6.1)^2 \times 0.02 \times 500 \times 60$ min/hr
  - = 16.1 mrem n/hr
- 6.4 cm polyethylene shielding required for 2 mrem/hr neutrons
  - Polyethylene TVL_n = 7.0 cm (E_{avg} = 0.35 MeV)
  - 2 mrem/hr = 16.1 mrem/hr $10^{-\#TVL}$
  - # TVL = 0.91 $\Rightarrow$ Polyethylene thickness = 0.91 × 7.0 = 6.4 cm

10 MeV Accelerators and Neutrons Example 3: Short Maze



- Measured neutron dose rate at door: 6.4 mrem / hr
  - At 200 cGy/min
  - d_1 = 15 ft, d_2 = 4.5 ft

Escape Maze



- On rare occasions a direct shielded door may stick in closed position with patient in treatment room
- Patient escape maze designed by David Patterson, Anderson Medical Center, Anderson, SC

Page 25

Escape Maze Measured Dose Rate

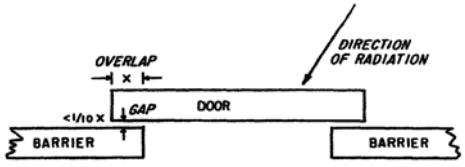
Beam Direction	Neutron (mrem/hr)	Photon (mrem/hr)	Total Neut. + Photon (mrem/hr)
Up	0.14	0.14	0.51
90°	0.80	0.37	1.17
Down	0.16	0.35	0.51
270°	0.10	0.52	0.62

- Measured with Varian 21EX with scattering phantom
  - 18 MV X-Ray, 400 monitor units / minute, 40x40cm beam
- Escape maze designed by David Patterson, Anderson Medical Center, Anderson,

Page 26

NCRP Report 51: Door Gap Rule

- NCRP 51 Rule: Overlap required = 10 × Door Gap



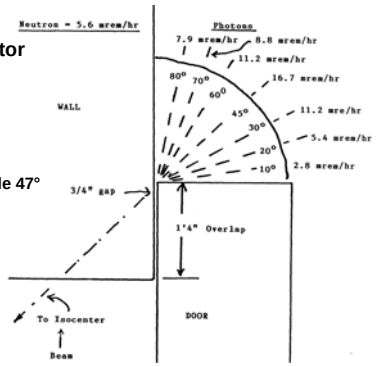
Overlap of Door with Wall

Caution: 1:10 door gap rule alone does not work for direct shielded door

Page 27

Gap and Edge Leakage

- 18 MV accelerator
- 600 MU/min
- 40x40 cm field
- Measured with phantom
  - Scattering angle 47°
- Dose rates measured at 1'



Page 28

Measurements at Direct Door Edge

Condition	X-ray Dose Rate (mrem/hr)	Radiation Types
40 x 40 field with phantom	16.7	head leakage, phantom scatter, room scatter, capture gammas
40 x 40 field, no phantom	3.45	head leakage, room scatter, capture gammas
0 x 0 field	2.87	head leakage, capture gammas

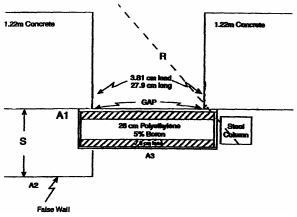
- 18 MV x-ray with 40 x 40 cm^2 and 0 x 0 cm^2 field
  - 600 cGy/min at isocenter with Gantry Angle = 270°
- Phantom scatter = run 1 – run 2 = 16.7 – 3.45 = 13.25 mrem/hr
- Room scatter = run 1 - (run 3 + Phantom scatter) = 0.58 mrem/hr

79% of dose rate is from Phantom Scatter

Page 29

Direct Shielded Door Parameters

- Door gap
  - Distance from the wall to the door, left & right as viewed from outside the door
- Minimum distance from isocenter to outside of door
  - Indicated by R
- Distance from wall barrier to outside of false wall
  - Indicated by S



Door	Gap right (cm)	Gap left (cm)	Overlap (cm)	Overlap ratio Right	Overlap ratio Left	R (m)	S (m)
1	-	-	19.0	-	-	5.79	0.76
2	2.2	2.2	21.6	0.10	0.10	6.71	1.07
3	1.0	1.5	20.3	0.05	0.07	7.32	1.52

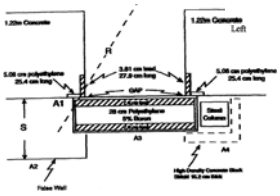
Next 3 charts are measurements for these 3 doors

Page 30

Measured Dose Rates for Door 1

- Photon & neutron dose equivalent rates
- Accelerator operating at 6.67 MU/ sec

Beam Direction	Location	Neutron (nSv/s)	Photon (nSv/s)	Total neutron plus photon (nSv/s)
Down	A1	-	-	-
	A2	5.28	3.47	8.75
	A3	1.50	0.42	1.92
	A4	0.25	0.42	0.67
Up	A1	-	-	-
	A2	2.72	3.44	6.16
	A3	0.86	0.69	1.55
	A4	0.14	0.50	0.64
Right	A1	-	-	-
	A2	5.06	2.94	8.00
	A3	1.69	0.44	2.13
	A4	0.53	0.39	0.92
Left	A1	-	-	-
	A2	3.14	4.17	7.31
	A3	0.58	3.61	4.19
	A4	0.19	0.31	0.50

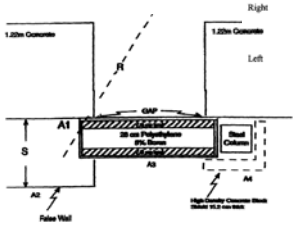


Page 31

Measured Dose Rates for Door 2

- Photon & neutron dose equivalent rates
- Accelerator operating at 6.67 MU/ sec
- No edge strips used

Beam Direction	Location	Neutron (nSv/s)	Photon (nSv/s)	Total neutron plus photon (nSv/s)
Down	A1	71.7	75.0	146.7
	A2	8.33	1.06	9.39
	A3	1.00	0.61	1.61
	A4	0.69	1.19	1.88
Up	A1	-	-	-
	A2	11.00	1.03	12.03
	A3	1.67	0.69	2.36
	A4	1.06	1.06	2.12
Right	A1	-	-	-
	A2	11.17	8.06	19.23
	A3	1.83	0.83	2.66
	A4	0.86	1.44	2.30
Left	A1	-	-	-
	A2	7.17	36.11	43.28
	A3	2.00	0.47	2.47
	A4	0.86	1.78	2.64

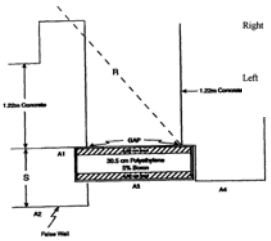


Page 32

Measured Dose Rates for Door 3

- Photon & neutron dose equivalent rates
- Accelerator operating at 6.67 MU/ sec

Beam Direction	Location	Neutron (nSv/s)	Photon (nSv/s)	Total neutron plus photon (nSv/s)
Down	A1	1.92	0.86	2.78
	A2	0.17	0.27	0.44
	A3	0.56	0.17	0.73
	A4	0.53	1.56	2.09
Up	A1	0.86	0.72	1.58
	A2	0.17	0.25	0.42
	A3	0.53	0.17	0.70
	A4	0.31	1.31	1.62
Right	A1	0.89	0.72	1.61
	A2	0.22	0.56	0.78
	A3	0.31	0.17	0.48
	A4	0.89	0.72	1.61
Left	A1	1.08	1.22	2.30
	A2	0.25	0.39	0.64
	A3	1.00	0.33	1.33
	A4	1.08	2.00	3.08



Page 33

HVAC Opening Options [1 of 2]

- Four options for Heating, Ventilation, and Air Conditioning (HVAC) penetration into treatment room
  - Most economical and safest systems are A, B, and C

A. Under floor slab
- Ducts located below the floor slab
- Penetration is at secondary barrier
- Penetration up into the room through the floor slab
- Shielding baffle may not be required

B. Above False Ceiling
- Independent HVAC system with air handler above false ceiling
- Requires 2 penetrations, each 12" x 12" for intake & return
- Penetration is at secondary barrier
- Located as close to ceiling slab as possible
- Shielding baffle not required

Page 34

HVAC Opening Options [2 of 2]

C. Multiple Penetrations
- HVAC enter treatment room through 3 or 4 small penetrations
- Penetrations in secondary barriers near ceiling slab
- Each penetration approximately 18" long x 12" high
- Penetrations angled away from isocenter
  - Prevents direct radiation from entering the openings
- Shielding baffle not required

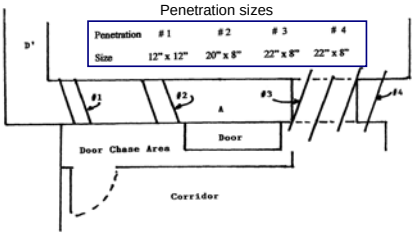
D. Shielding Baffle
- HVAC duct enters the room over the door
- Size of opening approximately 18" high by 42" long
- Located as close to ceiling slab as possible
- Penetration shielded with lead and polyethylene (5% boron)
  - Lead ~2" to 3" thickness, polyethylene ~2" to 4" thickness
- Shielding materials must abut concrete wall & ceiling
  - i.e., no wall board between shield and concrete

Page 35

Multiple HVAC Penetrations Example

Penetration sizes

Penetration	# 1	# 2	# 3	# 4
Size	12" x 12"	20" x 8"	22" x 8"	22" x 8"



- Four penetrations used to route HVAC
- Penetrations located in secondary barrier A as close to ceiling barrier as possible
- Each penetration angled 45° in horizontal direction

Page 36

HVAC Measurements

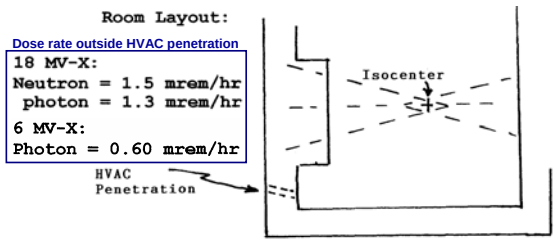
- HVAC routed through secondary barrier as shown
  - Intake & exhaust 12"x12" penetration each (located near ceiling slab)
- Dose rates measured outside HVAC penetration
  - Measured at 18 MV & 6 MV with 680 cGy/min at isocenter
  - 40x40 cm beam with scattering phantom in beam

Room Layout:

Dose rate outside HVAC penetration

18 MV-X:
Neutron = 1.5 mrem/hr
photon = 1.3 mrem/hr

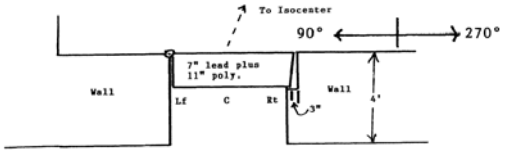
6 MV-X:
Photon = 0.60 mrem/hr



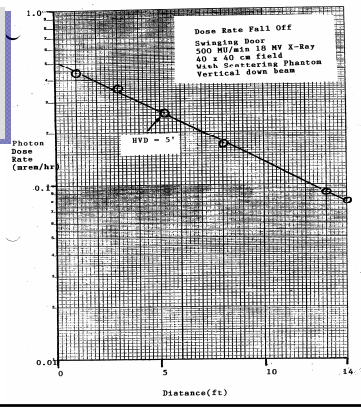
Measured Dose Rate with Hinged Door

- 18 MV x-ray
- 700 MU / minute
- 40 x 40 cm^2 field
- With scattering phantom
- Opening time 20 sec
- Close time 36 sec

Gantry Angle	NEUTRONS (nSv/h) Center	Right	PHOTONS (nSv/h) Center	Left
0°	6.81	2.99	1.71	1.51
90°	1.61	2.58	0.74	0.54
180°	2.80	1.75	-	-
270°	6.98	3.66	1.63	1.20



Dose Rate Fall Off for Swinging Door



Contact Information

Patton H. McGinley, Ph.D., A.B.R., A.B.H.P.
Certified Radiological Physicist
685 Tahoe Circle
Stone Mountain, GA 30083