Shielding Calculation Report
Varian iX
Methodist Hospital ~ Willowbrook
August 22, 2007

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MP 10019
1. **Introduction**

This report reviews the radiation shielding for the therapy rooms in a new facility being built in Willowbrook, Texas, by the Methodist Hospital System.

The center will begin with one linear accelerator and a vault for a second possible accelerator. The vault that is being built out is the south vault and all calculation points will be relative to this vault.

The calculations are based on the plans supplied by Carl Butler of Harrell Architects on 7/24/07. Any changes from the plans may invalidate the calculations.

2. **Linear Accelerator**

The accelerator is a Varian iX with On-Board-Imaging manufactured by Varian. The unit will be capable of producing 6 MV and 18 MV photons and electrons ranging from 6 MeV to 20 MeV. The accelerator is also capable of doing Intensity Modulated Radiation Therapy which will be discussed later. Electrons do not contribute to shielding requirements in the case of a linear accelerator that also produces photons.

The facility is attached to an office building, but there are no offices or useable space above the vaults. Currently no buildings are near the vaults themselves other than the one shown in the elevation plan. Addition of new buildings near the vaults may invalidate calculations. Floor and elevation plans used are found in Appendix 1.

3. **Shielding Design Goal**

The shielding design goals (P) are 0.02 mSv/week (1mSv/yr) for uncontrolled areas and 0.1 mSv/week (5mSv/yr) for controlled areas.

The maximum dose equivalent in any one hour (TADR) is 0.02 mSv (20µSv).

4. **Assumptions**

- The concrete density is 147 lbs./cu ft.
- Distances to calculation points are the distance from the target or isocenter to the wall + 1 foot. Ceiling distances are + 3 feet. Isocenter to target distance is 1 m.
- Primary and Leakage Tenth Value Layers (TVL) and Half Value Layers (HVL) are found below and are from NCRP Report #151 Tables B.2 and B.7.
<table>
<thead>
<tr>
<th>Energy (MV)</th>
<th>Radiation Source</th>
<th>TVL\textsubscript{1} \text{ (first Tenth Value Layer)}</th>
<th>TVL\textsubscript{e} \text{ (last Tenth Value Layer)}</th>
<th>HVL</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Cm</td>
<td>Inches</td>
<td>Cm</td>
</tr>
<tr>
<td>18</td>
<td>Primary</td>
<td>45</td>
<td>17.7</td>
<td>43</td>
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<tr>
<td>6</td>
<td>Primary</td>
<td>37</td>
<td>14.6</td>
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<tr>
<td>18</td>
<td>Leakage</td>
<td>36</td>
<td>14.2</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>Leakage</td>
<td>34</td>
<td>13.4</td>
<td>29</td>
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</tbody>
</table>

- Workload is the dose (Gy) per week at Isocenter and it is assumed that the conventional workloads, $W_{\text{conv}}$ are $W(6 \text{ MV}) = 300$ and $W(18 \text{ MV}) = 450$ Gy/week.

IMRT considerations:

$$W_L = W_{\text{conv}} + C * W_{\text{IMRT}}$$

Assume 80% of 6 MV patients are IMRT, and 40% of 18 MV patients are IMRT. $C$ is the monitor unit efficiency and is assumed to be 3. Therefore the workloads with IMRT are 780 Gy/week and 810 Gy/week respectively. Typically, conventional workloads will be used for primary barriers, and IMRT workloads will be used for scatter, leakage, and TADR calculations.

- Occupancy factors are given by table B1 of NCRP #151

5. **Summary** (full calculations are given in Appendix 2)

<table>
<thead>
<tr>
<th>Point</th>
<th>P</th>
<th>inches needed</th>
<th>inches present</th>
<th>ok?</th>
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<tbody>
<tr>
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<td>61.9 concrete</td>
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<td>Y</td>
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<td>B</td>
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<td>F</td>
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<td>32.5 concrete</td>
<td>63.8</td>
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<tr>
<td>I</td>
<td>Uncontrolled</td>
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<td>DOOR</td>
<td>Controlled</td>
<td>3.1” BPE &amp; 0.86” Pb</td>
<td>0</td>
<td>N</td>
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</tbody>
</table>

Locations of points are given below.
6. References

Appendix 1

Building North Section:

To face of existing building

BUILDING SECTION
North Section
Appendix II

- **Point A**

Description: Primary barrier along south wall
Occupancy factor (T): Parking lot = 1/40 = 0.025
Distance from Isocenter to point, d = 23.5' + 1' = 24.5' = 7.46m
Dose per week outside barrier (P) = uncontrolled = $20 \times 10^{-6}$ Sv
Use Factor (U) = .25

- **Primary Barrier Calculation**

Transmission factor of the primary barrier ($B_x$):

$$B_x (18\text{MV}) = \frac{P d^2_{pri}}{WUT} = \frac{20 \times 10^{-6} \times (7.46 + 1)^2}{450 \times .025 \times .25} = 5.09 \times 10^{-4}$$

Number of tenth value layers required ($n$):

$$n = -\log(B_x) = \log\left(\frac{1}{B_x}\right) = \log\left(\frac{1}{5.09 \times 10^{-4}}\right) = 3.29$$

Barrier thickness ($t$) is given by:
\[ t = TVL_1 + (n-1)TVL_c = 45 + (3.29-1) \times 43 = 143.6 \text{ cm} = 56.5" \]

When a barrier is thickness \( t \) is greater than the first TVL, the total transmission factor, \( B \), is given by:

\[
B_x = 10 \left\{ 1 - \left( \frac{t - TVL_c}{TVL_c} \right) \right\}
\]

To determine if this is adequate for the additional workload from 6 MV, the following are used:

\[
H(6MV) = B_x \frac{WUT}{d^2} = \frac{10 \left\{ 1 - \left( \frac{143.6-37}{33} \right) \right\} \times 300 \times .25 \times .025}{(7.46+1)^2} = 1.54 \times 10^{-6} \frac{Sv}{\text{week}} = 1.54 \frac{\mu Sv}{\text{week}}
\]

The 6 MV dose equivalent is only 8\% of the shielding design goal and will not affect the primary beam shielding.

- **TADR Calculation**

The maximum dose equivalent in any one hour is determined from the maximum absorbed dose rate at isocenter. This is \( \dot{D}_o = 12 \text{ Gy/min} \) or 720 Gy/hr. The instantaneous dose rate at location A with transmission factor \( B_x \) is:

\[
IDR(18MV) = \frac{\dot{D}_o \times B_x}{d^2} = \frac{720 \times 5.09 \times 10^{-4}}{(7.46+1)^2} = 5.12 \times 10^{-3} \frac{Sv}{\text{hr}}
\]

And

\[
IDR(6MV) = \frac{720 \times 10^{1 - \left\{ 1 - \left( \frac{143.6-37}{33} \right) \right\}}}{(7.46+1)^2} = 5.91 \times 10^{-4} \frac{Sv}{\text{hr}}
\]

The weekly time averaged dose equivalent rate, \( R_w \), is the time averaged dose rate at the location averaged over a 40 hour work week. It is as follows:

\[
R_w(18MV) = \frac{IDR \times WU}{\dot{D}_o} = \frac{5.12 \times 10^{-3} \times 450 \times .25}{720} = 8.00 \times 10^{-4} \frac{Sv}{\text{week}} = 800 \frac{\mu Sv}{\text{week}}
\]

And
The maximum number of patients per hour is 6. The average number of patients per hour is 5. \( M = \frac{6}{5} = 1.2 \). The dose equivalent in any one hour from both 6MV and 18MV patients is:

\[
R_p(6MV) = \frac{5.91 \times 10^{-4} \times 300 \times 0.25}{720} = 6.16 \times 10^{-5} \text{ Sv week} = 62 \mu\text{Sv week}
\]

This does not satisfy the 20\( \mu \text{Sv} \) in any one hour requirement. 1 HVL (18MV) must be added to meet the requirement.

\[
t = 143.6 \text{cm} + 13.5 \text{cm} = 157.1 \text{cm} = 61.9''
\]

**Scatter Dose Calculation**

For this patient scatter calculation, a position of 10° off the beam central axis is assumed. This is the worst case scenario because when the beam is pointing at point A the scatter fraction (\( \alpha \)) is highest and the energy of the small angle scattered radiation is also the highest. We will just consider 18 MV scatter due to the higher energy and penetration of the scatter beam.

Calculated slant thickness of barrier = 157.1 cm
Distance from target to patient, \( d_{sca} = 1 \text{m} \)
Distance from isocenter to point A = \( d_{sec} = 7.46 \text{m} \)
\( F = \) field area at mid depth of patient at 1m = 40x40 cm²
\( \alpha = \) Scatter fraction for 10° = 1.42x10⁻² from table B.4 of NCRP 151
TVL (18MV, scattered at 10°) = 45 cm concrete from table B.5a of NCRP 151

The maximum transmitted patient scattered dose equivalent at location A from 18 MV is:

\[
B_{sca} = 10^{\frac{t}{TVL}} = 10^{\frac{157.1}{45}} = 3.23 \times 10^{-4}
\]

Then

\[
H_{sca} = B_{sca} \alpha \frac{F}{400} \frac{WUT}{d_{sca}^2 d_{sec}^2} = \left(3.23 \times 10^{-4}\right) \left(1.42 \times 10^{-2}\right) \left(\frac{40 \times 40}{400}\right) \left(\frac{450 \times 0.25 \times 0.025}{1^2 \times 7.46^2}\right) = 9.27 \times 10^{-7} \text{ Sv week}
\]

The dose of 0.927 \( \mu \text{Sv/week} \) is well below the 20\( \mu \text{Sv/week} \) limit and is therefore negligible. The primary barrier is sufficient for patient scattered radiation.

**Leakage Radiation Calculation**

\( W = \) IMRT workloads given in part 4 - Assumptions
Use TVLs are the same as tabulated in part 4 – Assumptions

The transmitted 6 MV leakage dose equivalent is:

\[
H_L = \frac{B_L \cdot WT \cdot 10^{-3}}{d_L^2} = \frac{10^{-3}(780)(0.025)}{7.46^2} = 1.1 \times 10^{-3} \mu Sv/week
\]

And for 18MV:

\[
H_L = \frac{B_L \cdot WT \cdot 10^{-3}}{d_L^2} = \frac{10^{-3}(810)(0.025)}{7.46^2} = 5.76 \times 10^{-3} \mu Sv/week
\]

Both these values are well below the limit. Because the treatment head is generally shielded to better than 0.1%, the primary barrier is adequate for shielding from additional leakage radiation, even with additional workload from IMRT.

- Point B

Description: Primary barrier between vaults
Occupancy factor (T): Adjacent Treatment Room = 0.5
Distance from Isocenter to point, \( d = 22.5' + 1' = 23.5' = 7.16m \)
Dose per week outside barrier (P) = controlled area = \( 0.1 \times 10^{-3} \) Sv
Use Factor (U) = .25
Transmission factor of the primary barrier (B_x):

\[ B_x(18MV) = \frac{P_d^2}{WUT} = \frac{0.1*10^{-3} \times (7.16 + 1)^2}{450 \times 0.5 \times 0.25} = 1.18 \times 10^{-4} \]

Number of tenth value layers required (n):

\[ n = \log \left( \frac{1}{B_x} \right) = \log \left( \frac{1}{1.18 \times 10^{-4}} \right) = 3.9 \]

Barrier thickness (t) is given by:

\[ t = TVL_1 + (n - 1)TVL_c = 45 + (3.9 - 1) \times 43 = 170.8 cm = 67.2" \]

To determine if this is adequate for the additional workload from 6 MV, the following are used:

\[
H(6MV) = B_x \frac{WUT}{d^2} = 10^{-\left[1\left(\frac{170.8-37}{33}\right)\right]} \times 300 \times 0.25 \times 0.5 = 4.95 \times 10^{-6} \frac{Sv}{week} = 4.95 \frac{\mu Sv}{week}
\]

The 6 MV dose equivalent is only 5% of the shielding design goal and will not affect the primary beam shielding.

The instantaneous dose rate at point B with transmission factor B_x is:

\[
IDR(18MV) = \frac{D_0 \times B_x}{d^2} = \frac{720 \times 1.18 \times 10^{-4}}{(7.16 + 1)^2} = 1.28 \times 10^{-3} \frac{Sv}{hr}
\]

\[
IDR(6MV) = 720 \times 10^{-\left[1\left(\frac{170.8-37}{33}\right)\right]} = 9.51 \times 10^{-5} \frac{Sv}{hr}
\]

\[ R_w \] is as follows:

\[
R_w(18MV) = \frac{IDR \times WU}{D_0} = \frac{1.28 \times 10^{-3} \times 450 \times 0.25}{720} = 2.00 \times 10^{-4} \frac{Sv}{week} = 200 \frac{\mu Sv}{week}
\]

\[
R_w(6MV) = \frac{9.51 \times 10^{-5} \times 300 \times 0.25}{720} = 9.9 \times 10^{-6} \frac{Sv}{week} = 9.9 \frac{\mu Sv}{week}
\]

The dose equivalent in any one hour from both 6MV and 18MV patients is:
\[
R_h = \left( \frac{M}{40} \right) R_{x(\text{total})} = \left( \frac{1.2}{40} \right) \times (200 + 9.9) = 6.3 \frac{\mu Sv}{\text{hour}}
\]

This satisfies the 20\(\mu\)Sv in any one hour requirement.

- **Patient Scatter and Leakage Calculation**

As we have seen from point A, patient scatter and leakage doses are negligible when the point in question is behind a primary barrier. Therefore, the patient scatter and leakage calculations will not be duplicated for point B.

- **Point C**

Description: Secondary barrier along East wall directly behind Linac

Occupancy Factor: Parking Lot = 1/40 = .025

Use Factor = 1 for scatter barriers

\(W =\) IMRT workloads given in part 4 - Assumptions

Distance from target to patient, \(d_{\text{sca}} = 1\)m

Distance from isocenter to point C = \(d_{\text{sec}} = d_{L} = 16\)’ + 1’ = 17’ = 5.18m

Dose per week outside barrier (P) = uncontrolled = \(20 \times 10^{-6}\) Sv

- **Patient Scatter Calculation**

\(\alpha\) (18 MV) = Scatter fraction for 90\(^{\circ}\) = \(1.89 \times 10^{-4}\) from table B.4 of NCRP 151

\(\alpha\) (6 MV) = Scatter fraction for 90\(^{\circ}\) = \(4.26 \times 10^{-4}\) from table B.4 of NCRP 151

TVL (6 MV, scattered at 90\(^{\circ}\)) = 17 cm concrete from table B.5a of NCRP 151
TVL (18 MV, scattered at 90°) = 19 cm concrete from table B.5a of NCRP 151
F = field area at mid depth of patient at 1m = 40x40 cm²

For 6 MV the barrier thickness required is:

\[ B_{6M}(MV) = \frac{Pd_{sec}^2d_{esc}^2}{\alpha WUT F} = \frac{20 \times 10^{-6}(1^2)(5.18^2)}{4.26 \times 10^{-4}(780)(1,025)(400,400)} = 1.62 \times 10^{-2} \]

Then the number of TVLs is:

\[ n = \log \left( \frac{1}{B_{6M}} \right) = \log \left( \frac{1}{1.62 \times 10^{-2}} \right) = 1.79 \]

Barrier thickness (t) is given by:

\[ t = n \times TVL = 1.79 \times 17 = 30.4 \text{ cm} \]

For 18 MV x-rays we get:

\[ B_{18M}(MV) = \frac{Pd_{sec}^2d_{esc}^2}{\alpha WUT F} = \frac{20 \times 10^{-6}(1^2)(5.18^2)}{1.89 \times 10^{-4}(810)(1,025)(400,400)} = 3.51 \times 10^{-2} \]

Then the number of TVLs is:

\[ n = \log \left( \frac{1}{B_{18M}} \right) = \log \left( \frac{1}{3.51 \times 10^{-2}} \right) = 1.46 \]

Barrier thickness (t) is given by:

\[ t = n \times TVL = 1.46 \times 19 = 27.7 \text{ cm} \]

Since the scatter thicknesses required for 6 MV and 18MV are within 1 TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover patient scattered dose is:

\[ t' = t + 0.301(TVL) = 30.4 + (0.301)(19) = 36.1 \text{ cm} \]

- Leakage Calculation

\[ B_L(6MV) = \frac{P \times d_L^2}{10^{-3} \times WT} = \frac{20 \times 10^{-6}(5.18^2)}{10^{-3} \times 780 \times 0.025} = 2.75 \times 10^{-2} \]

Then the number of TVLs is:
Barrier thickness \( t \) is given by:

\[
t = 34 + (1.56 - 1) \times 29 = 50.3\text{cm}
\]

And for 18MV:

\[
B_L(18MV) = \frac{P \times d_i^2}{10^{-3} \times WT} = \frac{20 \times 10^{-6} \times (5.18^2)}{10^{-3} \times 810 \times .025} = 2.65 \times 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log \left( \frac{1}{B_s} \right) = \log \left( \frac{1}{2.65 \times 10^{-2}} \right) = 1.58
\]

Barrier thickness \( t \) is given by:

\[
t = 36 + (1.58 - 1) \times 34 = 55.6\text{cm}
\]

Since the leakage thicknesses required for 6 MV and 18MV are within one TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover leakage dose is:

\[
t' = t + 0.301(TVL) = 55.6 + (.301)(34) = 65.8\text{cm} = 25.9''
\]

The scattered radiation contributions are negligible and this wall can be shielded for IMRT leakage alone.

- **TADR Calculation**

The instantaneous dose equivalent rates for patient scatter are:

\[
IDR_{p3}(6MV) = \frac{\dot{D}_0 \alpha F}{400 \times d_{sca}^2} \times 10 \left( \frac{t}{TVL} \right) = \frac{720 \times 4.26 \times 10^{-4} \times 40 \times 40}{400 \times 5.18^2} \times 10 \left( \frac{65.8}{17} \right) = 6.12 \times 10^{-6} \text{Sv/hr}
\]

and

\[
IDR_{p3}(18MV) = \frac{\dot{D}_0 \alpha F}{400 \times d_{sca}^2} \times 10 \left( \frac{t}{TVL} \right) = \frac{720 \times 1.89 \times 10^{-4} \times 40 \times 40}{400 \times 5.18^2} \times 10 \left( \frac{65.8}{19} \right) = 6.95 \times 10^{-6} \text{Sv/hr}
\]

The instantaneous dose equivalent rates for leakage we have:
We find the scattered radiation contributions are insignificant at point C, so only leakage radiation contributions will be computed. The results are:

\[
IDR_{Leak}(6MV) = \frac{720 \times 10^{-3} \times 10}{5.18^2} = 2.14 \times 10^{-4} \frac{Sv}{hr}
\]

and

\[
IDR_{Leak}(18MV) = \frac{720 \times 10^{-3} \times 10}{5.18^2} = 3.56 \times 10^{-4} \frac{Sv}{hr}
\]

And therefore:

\[
R_w(6MV) = \frac{IDR_{Leak} \times W}{D_0} = \frac{2.14 \times 10^{-4} \times 780}{720} = 2.32 \times 10^{-4} \frac{Sv}{week} = 232 \frac{\mu Sv}{week}
\]

And

\[
R_w(18MV) = \frac{IDR_{Leak} \times W}{D_0} = \frac{3.56 \times 10^{-4} \times 810}{720} = 4.00 \times 10^{-4} \frac{Sv}{week} = 400 \frac{\mu Sv}{week}
\]

This is below the 20\(\mu\)Sv/hour limit.

- **Point D**

  Description: Outdoor courtyard secondary barrier along west wall
  Occupancy Factor: Outside, no seating = 1/40 = .025
  Use Factor = 1 for scatter barriers
  \(W\) = IMRT workloads given in part 4 - Assumptions
  Distance from target to patient, \(d_{sca}\) = 1m
  Distance from isocenter to point D = \(d_{sec} = d_{L} = 25.67' + 1' = 26.67' = 8.13\)m
  Dose per week outside barrier (P) = uncontrolled = 20 \(\times 10^{-6}\) Sv
As seen for point C, patient scatter will be negligible at this point. We will only consider leakage dose:

- **Leakage Calculation**

\[
B_L(6MV) = \frac{P \cdot d_i^2}{10^3 \cdot WT} = \frac{20 \cdot 10^{-6} \cdot (8.13^2)}{10^{-3} \cdot 780 \cdot .025} = 6.78 \cdot 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log \left( \frac{1}{B_s} \right) = \log \left( \frac{1}{6.78 \cdot 10^{-2}} \right) = 1.17
\]

Barrier thickness (t) is given by:

\[
t = 34 + (1.17 - 1) \cdot 29 = 38.9\,cm
\]

And for 18MV:

\[
B_L(18MV) = \frac{P \cdot d_i^2}{10^3 \cdot WT} = \frac{20 \cdot 10^{-6} \cdot (8.13^2)}{10^{-3} \cdot 810 \cdot .025} = 6.53 \cdot 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log \left( \frac{1}{B_s} \right) = \log \left( \frac{1}{6.53 \cdot 10^{-2}} \right) = 1.18
\]

Barrier thickness (t) is given by:

\[
t = 36 + (1.18 - 1) \cdot 34 = 42.3\,cm
\]
Since the leakage thicknesses required for 6 MV and 18MV are within one TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover leakage dose is:

\[ t' = t + 0.301(TVL) = 42.3 + (0.301)(34) = 52.5\text{cm} = 20.7''\]

Similar to point C, the instantaneous dose rate is below the limit.

- **Point E**

Description: Directly outside treatment room door
Occupancy Factor: control room door = 1/8 = .125
Distance from isocenter to point F = dL = 20.39' + 1' = 21.39' = 6.2m
Dose per week outside barrier (P) = controlled = 0.1 \times 10^{-3} \text{ Sv}

- **Leakage Calculation**

As seen for previous points, patient scatter will be negligible at this point. We will only consider leakage dose. Point E is complicated by the fact that dose through the door is also at this point and contributes to the 0.1mSv dose limit. Instead of calculating required barrier thickness, we will calculate the actual expected dose through the planned barrier. The existing barrier slant thickness, t, is 113.1 cm (44.5'').

\[
H(6MV) = \frac{10^{-3} \cdot BWT}{d^2} = \frac{10^{-3} \cdot 10 \cdot \left(1 + \frac{t}{TVL}\right)}{d^2} \cdot WT = 10^{-3} \cdot 10 \cdot \frac{1 + \{113.1-34\}}{29} \cdot 780 \cdot .125 \frac{\mu Sv}{\text{week}} = 0.47 \frac{\mu Sv}{\text{week}}
\]

And
Adding together, we get 1.85 µSv/week. We will find in the dose calculation for the door that compensating for the additional shielding by the steel encasing of the door will net us an extra 16 µSv/week that can be allotted for this dose requirement.

- **Point F**

Description: Linac control room  
Occupancy Factor: control room = 1  
Distance from isocenter to point F = d_L = 26.26' + 1' = 27.26' = 8.31 m  
Dose per week outside barrier (P) = controlled = 0.1*10^{-3} Sv  
As seen for previous points, patient scatter will be negligible at this point. We will only consider leakage dose:

### Leakage Calculation

\[
B_L(6MV) = \frac{P \cdot d_L^2}{10^{-3} \cdot WT} = \frac{0.1 \cdot 10^{-3} \cdot (8.31^2)}{10^{-3} \cdot 780 \cdot 1} = 8.85 \cdot 10^{-3}
\]

Then the number of TVLs is:

\[
n = \log \left( \frac{1}{B_L} \right) = \log \left( \frac{1}{8.85 \cdot 10^{-3}} \right) = 2.05
\]

Barrier thickness (t) is given by:

\[
t = 34 + (2.05 - 1) \cdot 29 = 64.5 cm
\]
And for 18MV:

\[ B_{L}(18MV) = \frac{P \cdot d_{L}^2}{10^{-3} \cdot WT} = \frac{1 \cdot 10^{-3} (8.31^2)}{10^{-3} \cdot 810 \cdot 1} = 8.53 \cdot 10^{-3} \]

Then the number of TVLs is:

\[ n = \log \left( \frac{1}{B_s} \right) = \log \left( \frac{1}{8.53 \cdot 10^{-2}} \right) = 2.07 \]

Barrier thickness (t) is given by:

\[ t = 36 + (2.07 - 1) \cdot 34 = 72.4 \text{ cm} \]

Since the leakage thicknesses required for 6 MV and 18MV are within one TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover leakage dose is:

\[ t' = t + 0.301(TVL) = 72.4 + (0.301)(34) = 82.6 \text{ cm} = 32.5'' \]

Similar to point C, the instantaneous dose rate is below the limit.

- **Point G**
  
  Description: Off primary wall at 30º away from primary beam  
  Occupancy Factor: Parking Lot = 0.025  
  Use Factor = \( \frac{1}{4} \) = .25  
  Distance from isocenter to point G = \( d_{sec} = d_{L} = 18.26' + 1' = 19.26' = 5.87 \text{ m} \)  
  Distance from target to isocenter = \( d_{sca} = 1 \text{ m} \)  
  Dose per week outside barrier (P) = uncontrolled = \( 20 \times 10^{-6} \text{ Sv} \)  
  \( \alpha \) (18 MV) = Scatter fraction for \( 30^\circ \) = \( 2.53 \times 10^{-3} \) from table B.4 of NCRP 151  
  \( \alpha \) (6 MV) = Scatter fraction for \( 30^\circ \) = \( 2.77 \times 10^{-3} \) from table B.4 of NCRP 151  
  TVL (6 MV, scattered at \( 30^\circ \)) = 26 cm concrete from table B.5a of NCRP 151  
  TVL (18 MV, scattered at \( 30^\circ \)) = 32 cm concrete from table B.5a of NCRP 151  
  \( F \) = field area at mid depth of patient at 1m = \( 40 \times 40 \text{ cm}^2 \)
\* Patient Scatter Calculation

For 6 MV the barrier thickness required is:

\[
B_{ps}(6MV) = \frac{Pd_{sec}^2 d_{sca}^2}{\alpha WUT} F = \frac{20 \times 10^{-6} \left(1^2\right)(5.87^2)}{2.77 \times 10^{-3}(780)(.25)(.025)}\left(\frac{400}{40 \times 40}\right) = 1.28 \times 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log\left(\frac{1}{B_s}\right) = \log\left(\frac{1}{1.28 \times 10^{-2}}\right) = 1.89
\]

Barrier thickness (t) is given by:

\[
t = n \times TVL = 1.89 \times 26 = 49.1 \text{ cm}
\]

For 18 MV x-rays we get:

\[
B_{ps}(18MV) = \frac{Pd_{sec}^2 d_{sca}^2}{\alpha WUT} F = \frac{20 \times 10^{-6} \left(1^2\right)(5.87^2)}{2.53 \times 10^{-3}(810)(.25)(.025)}\left(\frac{400}{40 \times 40}\right) = 1.35 \times 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log\left(\frac{1}{B_s}\right) = \log\left(\frac{1}{1.35 \times 10^{-2}}\right) = 1.87
\]
Barrier thickness (t) is given by:

\[ t = n \ast TVL = 1.87 \ast 32 = 59.8 \text{cm} \]

Since the scatter thicknesses required for 6 MV and 18MV are within 1 TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover patient scattered dose is:

\[ t' = t + 0.301(\text{TVL}) = 59.8 + (.301)(32) = 69.5 \text{cm} = 27.4'' \]

- Leakage Calculation

\[ B_L(6MV) = \frac{P \ast d_L^2}{10^{-3} \ast WT} = \frac{20 \ast 10^{-6}(5.87^2)}{10^{-3} \ast 780 \ast .025} = 3.53 \ast 10^{-2} \]

Then the number of TVLs is:

\[ n = \log \left( \frac{1}{B_s} \right) = \log \left( \frac{1}{3.53 \ast 10^{-2}} \right) = 1.45 \]

Barrier thickness (t) is given by:

\[ t = 34 + (1.45 - 1) \ast 29 = 47.1 \text{cm} \]

And for 18MV:

\[ B_L(18MV) = \frac{P \ast d_L^2}{10^{-3} \ast WT} = \frac{20 \ast 10^{-6}(5.87^2)}{10^{-3} \ast 810 \ast .025} = 3.40 \ast 10^{-2} \]

Then the number of TVLs is:

\[ n = \log \left( \frac{1}{B_s} \right) = \log \left( \frac{1}{3.40 \ast 10^{-2}} \right) = 1.47 \]

Barrier thickness (t) is given by:

\[ t = 36 + (1.47 - 1) \ast 34 = 51.9 \text{cm} \]

Since the leakage thicknesses required for 6 MV and 18MV are within one TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover leakage dose is:

\[ t' = t + 0.301(\text{TVL}) = 51.9 + (.301)(34) = 62.2 \text{cm} \]

Similar to point C, the instantaneous dose rate is below the limit.
• Point H

Description: Primary ceiling barrier  
Occupancy factor (T): roof = 1/40 = 0.025  
Distance from Isocenter to point, d = 14.57’ + 1’ = 15.57’ = 4.75m  
Dose per week outside barrier (P) = uncontrolled = 20*10^-6 Sv  
Use Factor (U) = .25

The roof is unoccupied open space and the primary beam currently does not point towards another building. The roof area is accessible by ladder only. It will occasionally have maintenance personnel working on the roof. If the amount of time spent on the roof is more than approximately 2 hrs/month during operational hours, the radiation oncology physicist should be notified. Furthermore, the barrier must be 11’ wide and run the full length of the roof in the direction of the primary beam swath.

![Diagram of Point H](image)

- **Primary Barrier Calculation**

Transmission factor of the primary barrier (Bx):

\[
B_x(18MV) = \frac{Pd_{pri}^2}{WUT} = \frac{20*10^{-6} \times (4.75 + 1)^2}{450 \times .025 \times .25} = 2.35 \times 10^{-4}
\]

Number of tenth value layers required (n):
Barrier thickness (t) is given by:

\[ t = TVL_e + (n - 1)TVL_e = 45 + (3.63 - 1) * 43 = 158\,\text{cm} = 62.2'' \]

When a barrier is thickness t is greater than the first TVL, the total transmission factor, B, is given by:

\[ B_x = 10 \left( \frac{t - TVL_e}{TVL_e} \right) \]

To determine if this is adequate for the additional workload from 6 MV, the following are used:

\[ H(6MV) = B_x \frac{WUT}{d^2} = 10 \left( \frac{1 + \left( \frac{158 - 37}{33} \right) }{1} \right) \times 300.25 \times 0.025 = 1.21 \times 10^{-6} \frac{Sv}{\text{week}} = 1.21 \frac{\mu Sv}{\text{week}} \]

The 6 MV dose equivalent is only 6% of the shielding design goal and will not effect the primary beam shielding.

- **TADR Calculation**

The maximum dose equivalent in any one hour is determined from the maximum absorbed dose rate at isocenter. This is \( D_o = 12\,\text{Gy/min} \) or 720 Gy/hr. The instantaneous dose rate at location A with transmission factor \( B_x \) is:

\[ IDR(18MV) = \frac{D_o \times B_x}{d^2} = \frac{720 \times 2.35 \times 10^{-4}}{(4.75 + 1)^2} = 5.12 \times 10^{-3} \frac{Sv}{\text{hr}} \]

And

\[ IDR(6MV) = \frac{720 \times 10}{(4.75 + 1)^2} = 4.68 \times 10^{-4} \frac{Sv}{\text{hr}} \]

The weekly time averaged dose equivalent rate, \( R_w \), is the time averaged dose rate at the location averaged over a 40 hour work week. It is as follows:
The maximum number of patients per hour is 6. The average number of patients per hour is 5. \( M = \frac{6}{5} = 1.2 \). The dose equivalent in any one hour from both 6MV and 18MV patients is:

\[
R_h = \left( \frac{M}{40} \right) R_{x(total)} = \left( \frac{1.2}{40} \right) \times (800 + 49) = 25.5 \, \mu\text{Sv/hour}
\]

This does not satisfy the 20\( \mu \text{Sv} \) in any one hour requirement. 1 HVL must be added to meet the requirement.

\( t = 158\, \text{cm} + 13.5\, \text{cm} = 171.5\, \text{cm} = 67.5'' \)

- Point I

Description: Secondary ceiling barrier
Occupancy factor (T): roof = \( \frac{1}{40} = 0.025 \)
Distance from Isocenter to point (\( d_{sec} \)): 16.74’ + 1’ = 17.74’ = 5.4m
Dose per week outside barrier (P) = uncontrolled = 20\( \times 10^{-6} \) Sv
Use Factor (U) = .25
\( \alpha \) (18 MV) = Scatter fraction for 30\(^\circ\) = 2.53\( \times 10^{-3} \) from table B.4 of NCRP 151
\( \alpha \) (6 MV) = Scatter fraction for 30\(^\circ\) = 2.77 \( \times 10^{-3} \) from table B.4 of NCRP 151
TVL (6 MV, scattered at 30\(^\circ\)) = 26 cm concrete from table B.5a of NCRP 151
TVL (18 MV, scattered at 30\(^\circ\)) = 32 cm concrete from table B.5a of NCRP 151
\( F \) = field area at mid depth of patient at 1m = 40x40 cm\(^2\)
IMRT workloads are used.
Patient Scatter Calculation

For 6 MV the barrier thickness required is:

\[
B_{ps}(6MV) = \frac{Pd_{sec}^2 d_{sca}^2}{\alpha WUT} \frac{400}{F} = \frac{20 \times 10^{-6} (5.4^2)}{2.77 \times 10^3 (780)^{\frac{1}{2}} (0.25) (0.025) (40 \times 40)} = 1.08 \times 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log\left(\frac{1}{B_s}\right) = \log\left(\frac{1}{1.08 \times 10^{-2}}\right) = 1.97
\]

Barrier thickness (t) is given by:

\[
t = n \times TVL = 1.97 \times 26 = 51.2 \text{ cm}
\]

For 18 MV x-rays we get:

\[
B_{ps}(18MV) = \frac{Pd_{sec}^2 d_{sca}^2}{\alpha WUT} \frac{400}{F} = \frac{20 \times 10^{-6} (5.4^2)}{2.53 \times 10^3 (810)^{\frac{1}{2}} (0.25) (0.025) (40 \times 40)} = 1.14 \times 10^{-2}
\]

Then the number of TVLs is:

\[
n = \log\left(\frac{1}{B_s}\right) = \log\left(\frac{1}{1.14 \times 10^{-2}}\right) = 1.94
\]

Barrier thickness (t) is given by:

\[
t = n \times TVL = 1.94 \times 32 = 62.08 \text{ cm}
\]

Since the scatter thicknesses required for 6 MV and 18MV are within 1 TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover patient scattered dose is:

\[
t' = t + 0.301(TVL) = 62.08 + (0.301)(32) = 71.7 \text{ cm} = 28.2" 
\]

Leakage Calculation

\[
B_{L}(6MV) = \frac{P \times d_{sec}^2}{10^{-3} \times WT} = \frac{20 \times 10^{-6} (5.4^2)}{10^{-3} \times 780 \times 0.025} = 2.99 \times 10^{-2}
\]

Then the number of TVLs is:
\[ n = \log\left(\frac{1}{B_s}\right) = \log\left(\frac{1}{2.99 \times 10^{-2}}\right) = 1.52 \]

Barrier thickness (t) is given by:

\[ t = 34 + (1.52 - 1) \times 29 = 49.2 \text{ cm} \]

And for 18MV:

\[ B_L(18MV) = \frac{P \times d_i^2}{10^{-3} \times WT} = \frac{20 \times 10^{-6} \times (5.4^2)}{10^{-3} \times 810 \times 0.025} = 2.88 \times 10^{-2} \]

Then the number of TVLs is:

\[ n = \log\left(\frac{1}{B_s}\right) = \log\left(\frac{1}{2.88 \times 10^{-2}}\right) = 1.54 \]

Barrier thickness (t) is given by:

\[ t = 36 + (1.54 - 1) \times 34 = 54.4 \text{ cm} \]

Since the leakage thicknesses required for 6 MV and 18MV are within one TVL of each other, one HVL needs to be added according to the two source rule. Therefore, the total shielding to cover leakage dose is:

\[ t' = t + 0.301(\text{TVL}) = 54.4 + (0.301)(34) = 64.6 \text{ cm} \]

Similar to point C, the instantaneous dose rate is below the limit.

- **Maze Door**

The dose at the treatment vault door is due to a contribution of photons and neutron doses. The dose equivalent at the door, \( H_d \) is given by:

\[ H_d = fH_s + H_{LS} + H_{PS} + H_{LT} \]

Each contribution will be calculated separately and then summed together.

- **Wall Scattered Radiation Component, \( H_S \)**

The ceiling is 15’10” = 4.83m
Normal use workloads will be used for this calculation.
\( U = 0.25 \)
\( d_G = \) perpendicular distance from the target to the first reflection surface = 15.58” = 4.75 m
\[ H_S = \frac{WU \alpha_0 \alpha_z A_0 A_Z}{(d_c d_r d_z)^2} = \left[ (450 \times 1.6 \times 10^{-3}) + (300 \times 2.7 \times 10^{-3}) \right] \times 0.25 \times 3.8 \times 8 \times 10^{-3} \times 11.6 = 6.01 \mu Sv \text{ week} \]

- Single Scattered Head Leakage Component, \( H_{LS} \).
Head leakage can scatter once against the wall and reach the maze door. IMRT workloads will be used for this calculation.

\[ U = 0.25 \]
\[ L_f = \text{head leakage radiation ratio} = 0.1\% \text{ per IEC 2002 requirement} \]
\[ A_1 = \text{area of wall seen from maze door} = 11.33' \times 15.83' = 16.63 \text{ m}^2 \]
\[ d_{zz} = \text{centerline distance along maze} = 9.26\text{m} \]
\[ d_{LS} = \text{distance from target to wall along maze centerline} = 8.59\text{ m} \]
\[ \alpha_1 (6\text{MV}) = \text{reflection coefficient for scatter of leakage radiation from wall (from Table B.8b from NCRP 151) for } 45^\circ \text{ incidence and } 0^\circ \text{ reflection} = 6.4 \times 10^{-3}. \]
\[ \alpha_1 (18\text{MV}) = \text{reflection coefficient for scatter of leakage radiation from wall (from Table B.8b from NCRP 151) for } 45^\circ \text{ incidence and } 0^\circ \text{ reflection} = 4.5 \times 10^{-3}. \]

The dose equivalent at the maze door from head leakage is thus:

\[
H_{LS} = \frac{L_f W U \alpha_1 A_1}{(d_{sec} d_{zz})^2} \approx 10^{-3} \left( \left( 780 \times 6.4 \times 10^{-3} \right) + \left( 810 \times 4.5 \times 10^{-3} \right) \right) \times 0.25 \times 16.63 \approx 5.67 \mu\text{Sv per week}
\]

- **Patient Scattered Radiation Component, \( H_{PS} \).**

Normal workloads will be used for this calculation.

\[ U = 0.25 \]
F = 40x40 cm²

A₁ = area of wall seen from maze door = 11.33´ x 15.83´ = 16.63 m²

dzz = centerline distance along maze = 9.26m

d_{sec} = distance from isocenter to wall along maze centerline = 26.57´=8.1m

a₁(6MV) = The 6 MV scatter fraction at 45° scatter angle (from Table B.4 from NCRP 151) = 1.39x10⁻³.

a₁(18MV) = The 18 MV scatter fraction at 45° scatter angle (from Table B.4 from NCRP 151) = 8.64x10⁻⁴.

α₁ = the concrete wall reflection coefficient for incident angle 45° and reflection angle of 0° for 0.5 MeV monoenergetic photons (NCRP 151 table B.8b) = 2.22x10⁻²

The 6 and 18 MV patient scatter contributions are:

\[
H_{ps} = \frac{a(\theta)WU \frac{F}{400} \alpha_1A_1}{(d_{sec}d_{zz})^2} = \frac{\left[(780 \times 1.39 \times 10^{-3}) + (810 \times 8.64 \times 10^{-4})\right] \times 0.25 \times \frac{40 \times 40}{400} \times 2.22 \times 10^{-2} \times 16.63}{(1 \times 9.26 \times 8.1)^2} =
\]

\[
H_{ps} = 116 \frac{\mu Sv}{week}
\]
**Head Leakage Radiation Through the Maze Wall, H_{LT}**

IMRT workloads will be used for this calculation.

- \( U = 0.25 \)
- \( L_f = \) head leakage radiation ratio = 0.1\% per IEC 2002 requirement
- \( d_{L} = \) distance from target to center of maze door through the inner maze wall = 21.66´= 6.6 m
- \( t = \) the oblique wall slant thickness = 2.89´= 88 cm
- TVLs are as given in Assumptions.

Calculating 18MV first, we find the barrier transmission for slant thickness \( t \) is:

\[
B_x(18MV) = 10 \left( 1 + \left( \frac{t}{TVL} \right) \right) = 10 \left( 1 + \frac{88}{34} \right) = 2.96 \times 10^{-3}
\]

Then the dose equivalent is

\[
H_{LT}(18MV) = \frac{L_f WUB}{d_L^2} = \frac{10^{-3} \times 810 \times 0.25 \times 2.96 \times 10^{-3}}{6.6^2} = 13.7 \ \mu Sv \text{ week}^{-1}
\]

Similarly for 6 MV:

\[
B_x(6MV) = 10 \left( 1 + \left( \frac{t}{TVL} \right) \right) = 10 \left( 1 + \frac{88}{29} \right) = 1.37 \times 10^{-3}
\]

Then the dose equivalent is

\[
H_{LT}(6MV) = \frac{L_f WUB}{d_L^2} = \frac{10^{-3} \times 780 \times 0.25 \times 1.37 \times 10^{-3}}{6.6^2} = 6.15 \ \mu Sv \text{ week}^{-1}
\]
Total dose equivalent at the wall due to leakage through the inner maze wall is 13.7 + 6.15 = 20µSv/week.

The fraction of the primary radiation transmitted through the patient is represented by \( f \) and is assumed to be 0.34 for a high energy Linac. When use factors are employed for dose equivalent considerations, the total is not 4*\( H_{tot} \). It is estimated as 2.64*\( H_{tot} \) (McGinley, 2002). The total dose equivalent due to scatter and leakage radiations, \( H_{tot} \) is then:

\[
H_{tot} = 2.64 \times H_d = 2.64 \left( fH_s + H_{LS} + H_{PS} + H_{LT} \right) = 2.64 \times \left( 6.01 + 5.67 + 116 + 20 \right) = 389 \frac{\mu S}{\text{week}}
\]

- **Neutron Capture Gamma-Ray Dose Equivalent at Maze Door**

Photoneutron production and neutron capture is proportional to the leakage radiation workload of high-energy x-rays (18 MV).

First, the area of the room must be known.
Average ceiling height = 14´ = 4.27m
Average room length = 23.8´ = 7.25m
Average room width = 25.5´ = 7.77m

\[
S_r = 2 \times \left( 4.27 \times 7.25 \right) + \left( 4.27 \times 7.77 \right) + \left( 7.77 \times 7.25 \right) = 241 \text{m}^2
\]
- Total neutron fluence per isocenter x-ray Gray at inner maze point, $\Phi_A$:

$$Q_n = \text{neutron source strength in neutrons emitted from the accelerator head per gray of x-ray absorbed dose at the isocenter} = 1.0 \times 10^{12} \text{ for a Varian iX model.}$$

d_1 = \text{distance from isocenter to center of maze} = 6.57\text{m}$$

$$\beta = \text{neutron transmission through linac head} = 1 \text{ for Lead housing}$$

$$\Phi_A = \frac{\beta Q_n}{4\pi d_1^2} + \frac{5.4 \beta Q_n}{2\pi S_r} + \frac{1.3 Q_n}{2\pi S_r} = \frac{1.0 \times 10^{12}}{4\pi \times 6.57^2} + \frac{5.4 \times 1.0 \times 10^{12}}{2\pi \times 241} + \frac{1.3 \times 1.0 \times 10^{12}}{2\pi \times 241} = 6.27 \times 10^9 \text{ neutrons per m}^2$$

- Photon Dose Equivalent Calculation at the Maze Door, $h_\phi$:

$$K = \text{ratio of neutron capture gamma-ray dose equivalent to the total neutron fluence} = 6.9 \times 10^{-16} \text{ Sv/m}^2 \text{ (NCRP 151)}$$

$$\Phi_A = \text{neutron fluence, found above}$$

d_2 = \text{distance along maze} = 21.7\text{´} = 6.61\text{m}$$

$$\text{TVD} = \text{Tenth Value Distance for photons} = 5.4 \text{ m for x-rays from 18-25 MV.}$$

$$h_\phi = K\Phi_A 10^{\left(\frac{d_2}{\text{TVD}}\right)} = 6.9 \times 10^{-16} \times 6.27 \times 10^9 \times 10^{\left(\frac{6.61}{5.4}\right)} = 2.58 \times 10^{-7} \frac{\text{Sv}}{\text{Gy}}$$

- Weekly neutron capture gamma-ray dose equivalent at the door, $H_{cg}$:

$$H_{cg} = Wh_\phi = 810 \times 2.58 \times 10^{-7} = 2.09 \times 10^{-4} = 209 \mu\text{Sv per week}$$

- Neutron dose equivalent at the door, $H_{n,D}$:

$$S_0 = \text{inner maze cross sectional area} = 15\text{´10} \times 12.42\text{´} = 18.31 \text{ m}^2$$

$$S_1 = \text{cross sectional area along maze} = 15\text{´10} \times 7.17\text{´} = 10.58 \text{ m}^2$$

The Tenth Value Distance for the Maze will be determined by:

$$\text{TVD} = 2.06\sqrt{S_1} = 2.06\sqrt{10.58} = 6.7 \text{m}$$

The neutron dose equivalent will be calculated by the method of Wu & McGinley (2003):

$$H_{n,D} = 2.4 \times 10^{-15} \Phi_A \sqrt{\frac{S_0}{S_1}} \left[1.64 \times 10^{1.9} + 10 \frac{d_2}{\text{TVD}}\right] = 2.4 \times 10^{-15} \times \left(6.27 \times 10^9\right) \left[18.31 \times 10.58\right] \left[1.64 \times 10^{1.9} + 10 \frac{6.61}{6.7}\right]$$
The weekly dose equivalent $H_n$ at the door due to neutrons is $W*H_n$:

$$H_n = WH_{n,D} = 810 \times 2.05 = 1660 \frac{\mu Sv}{\text{week}}$$

- **Total Dose Equivalent at the Maze Door $H_w$:**

$$H_w = H_{TOT} + H_{cg} + H_n = 389 + 209 + 1660 = 2258 \frac{\mu Sv}{\text{week}}$$

- **Shielding Barrier for Maze Door:**

The maze entrance is located in a controlled area and the shielding design goal is 0.1mSv/week. The TVL for scatter and leakage photons, $H_{TOT}$, varies between 3-6 mm of Pb depending on maze length. The TVL for neutron capture gamma rays, $H_{cg}$, can be as much as 61 mm of Pb (NCRP, 1984). We will assume the shielding for the neutron capture rays will suffice for the scattered and leakage radiation. We will set 30% of our allowable dose to be from neutrons, and 70% from the capture gammas. We will then have:

$$n(H_n) = \log\left(\frac{1660}{30}\right) = 1.73$$

And

$$n(H_{cg}) = \log\left(\frac{209}{70}\right) = 0.475$$

The TVL for Borated Polyethylene is 45mm. We then get:

$$t(H_n) = 1.73 \times 45 = 78.8\text{mm} = 3.1" \text{BPE}$$

The BPE is on the inside of the door, followed by the lead. 3" of BPE allows about 77% transmission of capture gamma rays of the equivalence of 7.1mm of Pb. We find we need:

$$t(H_{cg}) = 0.475 \times 61 = 28.98\text{mmPb} \Rightarrow 28.98 - 7.1 = 21.88\text{mmPb} = 0.86" \text{Pb}$$

This calculation neglects the steel casing on the door, which is $1/4"$ on each side for a total of $1/2"$ of steel. The TVL of steel is 0.108m (McGinley) or 4.25". The amount of radiation that is attenuated by this is:
\[ \%_{\text{attenuated}} = 1 - \left( 10^{\frac{1}{4.25}} \right) = 1 - \left( 10^{\frac{0.50}{4.25}} \right) = 23.7\% \]

Our allowed dose through the door was 0.1mSv, 70% of which are capture gammas that are also attenuated by the steel. Therefore, we have overshielded the door by:

\[ H = 0.1mSv \times 0.70 \times 0.237 = 0.0166mSv = 16.6\mu Sv \]

This dose is the extra allowable dose that will added to point E.