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Design and Shielding considerations for an Image Guided Brachytherapy (IGBT) suite

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ABSTRACT

Purpose: Image Guided Brachytherapy (IGBT) in a dedicated suite allows applicator placement, planning and treatment delivery in a single room, minimizing the patient movement during the process. The design and shielding considerations for the new IGBT suite are presented.

Methods: The suite is designed primarily for High-Dose-Rate (HDR) brachytherapy using an Ir-192 source integrated with a CT-on-rails imaging system. The shielding design constraints are 0.02 mSv/week (1 mSv/year) for uncontrolled areas and 0.1 mSv/week (5 mSv/year) for controlled areas. For a 12Ci source, Γ =4.69 R/(mCih) at 1 cm, fmed=0.96 cGy/R, t=10 hr/wk (40 patients/week* 15 min/patient*(1 hour/60 minutes), workload = 0.5 Gy/Wk. To maintain conservatism, the workload was increased by 30% to account for additional non-HDR contributions, including CT imaging and low-dose-rate procedures. The shielding calculations are provided for the points at a perpendicular distance from the isotopic Ir-192 source at the center of the suite. To be on the conservative side, a use factor of 1 and occupancy factors of 1 (control room, staff office) and 1/5 (janitor's closet/staff toilet) are used.

Results: For points specified in the calculation, the wall shielding requirements with normal concrete are 38.3 cm (control room), 42.1 cm (staff offices), 38.3 cm (staff toilet), 31.8 cm (janitor's closet) and 40.5 cm (duct point). The vault door is comprised of 2 inches of lead sandwiched between ¼ inches of steel and duct penetrations will be lead-lined to ensure equivalent safety measures. The walls and ceiling of the new vault will be 2 ft concrete (60.9 cm) which is more than adequate barrier per the NRC recommendations

Conclusion: A strictly conservative approach has been presented for the planned IGBT suite shielding. The proposed vault construction provides substantial safety margins and ensures compliance with regulatory limits for both occupational workers and members of the public. Shielding requirements with a strictly conservative approach have been presented for the planned IGBT suite. The proposed vault shielding will provide more than adequate barrier to protect members of the public and occupational workers from mandated regulatory limits.

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INTRODUCTION

A dedicated IGBT suite integrates applicator placement, planning, and delivery into one room, minimizing intra-procedural patient movement.

Our institution is building a new IGBT equipped High-Dose-Rate (HDR) Brachytherapy suite. The HDR Brachytherapy unit will be relocated from its current location to the new vault, that will be housed with a dedicated on-rails Computed Tomography (CT) scanner (sliding gantry, 20/64 slice configuration) capable to allow an IGBT workflow. The design and shielding considerations for the new IGBT suite are presented.

METHODS AND MATERIALS

The suite is designed primarily for HDR brachytherapy using an Ir-192 source integrated with a CT-on-rails imaging system. The shielding design constraints are 0.02 mSv/week (1 mSv/year) for uncontrolled areas and 0.1 mSv/week (5 mSv/year) for controlled areas [1-3].

The dose per week required outside a barrier for protection (P, Sv/week) is related to the barrier transmission factor (B) by the equation [1-2],

$$B = \frac{Pd^2}{WUT}$$

Where P is the design dose limit (Sv/wk), d is the distance from source to point of interest, W is the workload (Gy/wk at 1 meter), U is the use factor (fraction of time per week the beam is directed at the barrier), and T is the occupancy factor (the fraction of time that the maximally exposed individual will be in the area outside the barrier per week).

For HDR treatments using 192Ir isotope, shielding assessments depend on the clinical workload calculated in Gy/wk. The current typical workload in our clinic is 6 patients per week, with an average treatment time of 10 minutes per treatment. For shielding design purposes, a highly conservative maximum workload of 40 patients per week at treatment time of 15 minutes per patient was assumed, substantially exceeding routine HDR patient treatment.

For a 12 Ci source, Exposure Rate Constant =4.69 $Rcm^2/(mCi.h)$ at 1 cm [Gamma Constant Γ = 0.469 $Rm^2/(Ci.h)$ at 1meter], f_{med}=0.96 cGy/R, t=10 hr/wk (40 patients/week* 15 min/patient*(1 hour/60 minutes), workload = 0.5 Gy/Wk.

RESULTS

For the calculations, workload =0.62 Gy/Wk, was used. This includes an additional 15% to the calculated workload (to account for any contributions from the non-HDR radiation in the room (CT scans, LDR procedures). This is a very conservative approach to ensure ample safety margins. This workload is cautiously picked and is much higher than the reported values for typical HDR workloads of 1-2 Gy/yr [3].

The shielding calculations are provided in Table 1. With P= 100 or 20µSv/wk and concrete TVL=14.7 cm, the required concrete thickness is less than the proposed thickness of the walls (2 ft=61 cm).

The Tenth Value Layers (TVL) used are Concrete=14.7 cm, Steel=4.9 cm and Lead=2 cm. The location of the HDR treatments was assumed to take place in the center of the vault . Below the vault is earth. Earth's soil and rock naturally attenuate gamma and X-rays which provide an excellent shield for radiation. The minimum distance to the occupied area from a shielded wall is assumed to be 0.3 m (≈ 1.0 ft). This is typically a conservatively safe estimate for most walls and especially for doors. Hence, the distances to the calculation points are distance from the source to the wall + 1 foot [1,2]. For example, the calculation point G is at 11.5 ft from the radiation isocenter (8.5 ft to the side wall + proposed wall thickness of 2 ft+1 ft extra per Ref [1,2]), see Fig. 1. All points other than A, D, G and J are at a larger distance and receive radiation obliquely. This will reduce the required shielding thickness and hence perpendicular incident point calculations are sufficient.

Use factor T=1, Occupancy factor =1 for control room, admin offices (assuming all people at all points of interest will stay there all time), Occupancy factor = 1/5 for gift shop area above mechanical/electrical duct. Occupancy factor = 1/5 for staff toilet, janitor's closet and occupancy factor= 1/2 for first floor area (patient toilet, patient corridor)

All areas adjacent to the vault are calculated with the NRC exposure limits. For control room and mechanical/electrical penetration point, design goal P= 100 µSv/wk (occupational limit). For all other areas, shielding design goal P = 20 µSv/wk (public limit). This provides stringent requirements for shielding as regulated by the NRC.

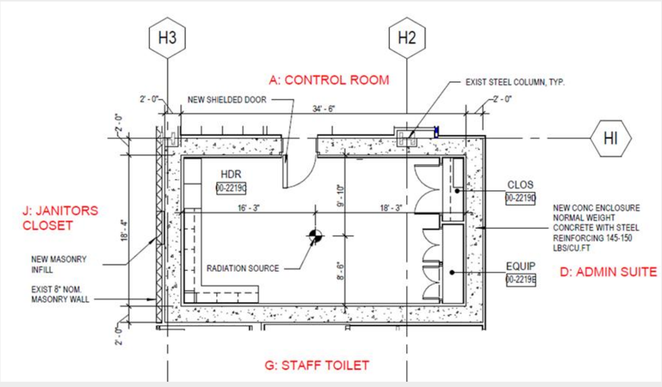

Fig 1: Architectural drawing depicting calculation points. Points A, D, G and J are used for the calculations as they are at a shorter distance than any other oblique points. Blueprint Courtesy of Smith Inc

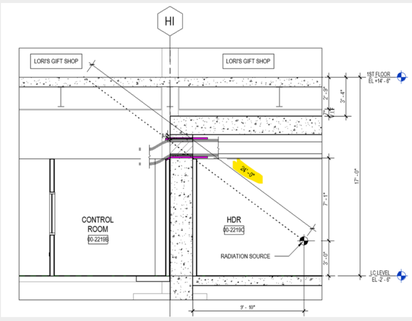

Fig 2: Facility drawing of the HVAC penetration. The largest penetration is 34" wide by 22" high and gift shop is 24 ft from the location of the radiation source.

Calc points	Distance (ft)	Distance (m)	P (µSv/wk)	Transmission B	n (#of TVLs)	Req concrete thickness (cm)
A (Control room)	12.17	3.71	100.0	2.47E-03	2.6	38.3
D (Admin offices)	20.25	6.17	20.0	1.37E-03	2.9	42.1
G (Staff toilet)	12.17	3.71	20.0	2.47E-03	2.6	38.3
J (Janitor's closet)	20.25	6.17	20.0	6.85E-03	2.2	31.8
Duct point	10.25	3.12	100.0	1.75E-03	2.8	40.5

Table 1: Required shielding thickness for the adjacent areas to the proposed HDR vault. Calculation points correspond to the points in Fig. 1. Duct point is the distance to the largest proposed penetration as shown in Fig. 2.

DISCUSSION

The planned 2 ft normal concrete is adequate shielding for the walls and ceiling. The door shielding will be comprised of two ¼ inch steel plates with 2 inches of lead sandwiched in between. Provided door shielding = (¼ +¼) inch steel + 2-inch Lead = 1.27cm Steel + 5.08cm Pb = 0.26TVL + 2.54TVL = 2.8TVL. The planned number of TVLs (2.8TVL) is greater than calculated TVLs, (see Table 1, 6th column, 2.6 TVLs) hence no additional shielding is required for the door.

The penetrations for mechanical and electrical connections are designed to be in the corner of the room. The largest concrete opening is 34" wide and 22" high (see Figure 2). Above the duct area, there is an existing 1.6 ft (48.8 cm) concrete lid. In the worst-case scenario, if the radiation misses all the inner concrete ceiling and only goes through open space, the x-rays will travel an oblique path to the level above. The Lori's gift shop above the duct area is 24 ft from the source of radiation and would need 30.4 cm of concrete to provide ample shielding (see column 7, Table 1). The existing 48.8 ft concrete above the duct provides adequate shielding, hence there is no extra lead shielding required to reduce duct radiation penetration.

CONCLUSIONS

We have adopted a rigorously conservative methodology for the planned IGBT suite shielding. The proposed HDR vault design delivers comprehensive protection across all structural frameworks including the walls, door, and penetrations.

The planned shielding measures ensure that radiation exposure to both public and occupational workers remain well below the dose limits recommended by the NRC 10 CFR 20 regulations.

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