Radiation Oncology Treatment Vault Design

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Acknowledgement

- Robert Barish
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Therapy Shielding Calculations Are Primarily Based on NCRP Report No. 151

- Report Title: "Structural Shielding Design and Evalua
  for Megavoltage X- and Gamma-Ray Radiotherapy Facilities"
  - Released December 31, 2005
- Calculations here illustrate the NCRP 151 recommendations
- Previous NCRP reports are also cited in some cases
  - e.g., NCRP 51 and NCRP 79

NCRP 151 recommendations are addressed throughout this presentation

Basic Shielding Concepts

- Establish a target dose-rate at a certain point behind a barrier
- Calculate barrier thickness necessary to achieve the target dose rate

Target Dose Rate P

Group Limits	ICRP 60 Dose limit (mSv/y)	ALARA Target limit (mSv/y)
Controlled	20	5
Uncontrolled	1	1

Area Limits

2 mr in any 1 hour

*1 year has 50 weeks of 40 hrs/week or 2000 hr/year

ALARA

- As Low As Reasonably Achievable
- ICRP 60 recommendations are limits
- Facilities should not be designed to the limits as they are not designed to be exceeded
- So ALARA factor of 10 - 20 can be applied

Occupancy Factor T

T	Type of area
1	Full Offices, shops, labs, living area
1/2	Adjacent treatment room, patient examination room adjacent to shielded vault
1/8	Treatment vault doors
1/20	Public toilets, unattended vending rooms, storage areas, outdoor areas with seating, unattended waiting rooms, patient holding areas, attics, janitors' closets
1/40	Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), stairways, unattened eleavtors

Use Factor *U*

Angle Interval Center	*U* (%)
90 degree interval	
0 degree (down)	*31.0*
90 and 270 degrees	*21.3 (each)*
180 degrees (up)	*26.3*
45 degree interval	
0 degrees (down)	*25.6*
45 and 315 degrees	*5.8(each)*
90 and 270 degrees	*15.9(each)*
135 and 225 degrees	*4.0(each)*
180 degrees (up)	*23*

Shielding Considerations

- Type of radiation
- Primary beam incidence
- Primary beam scatter
- Patient scatter
- Leakage radiation

Shielding Considerations

- Type of space
  - Basement
  - Mountain
  - 3rd floor

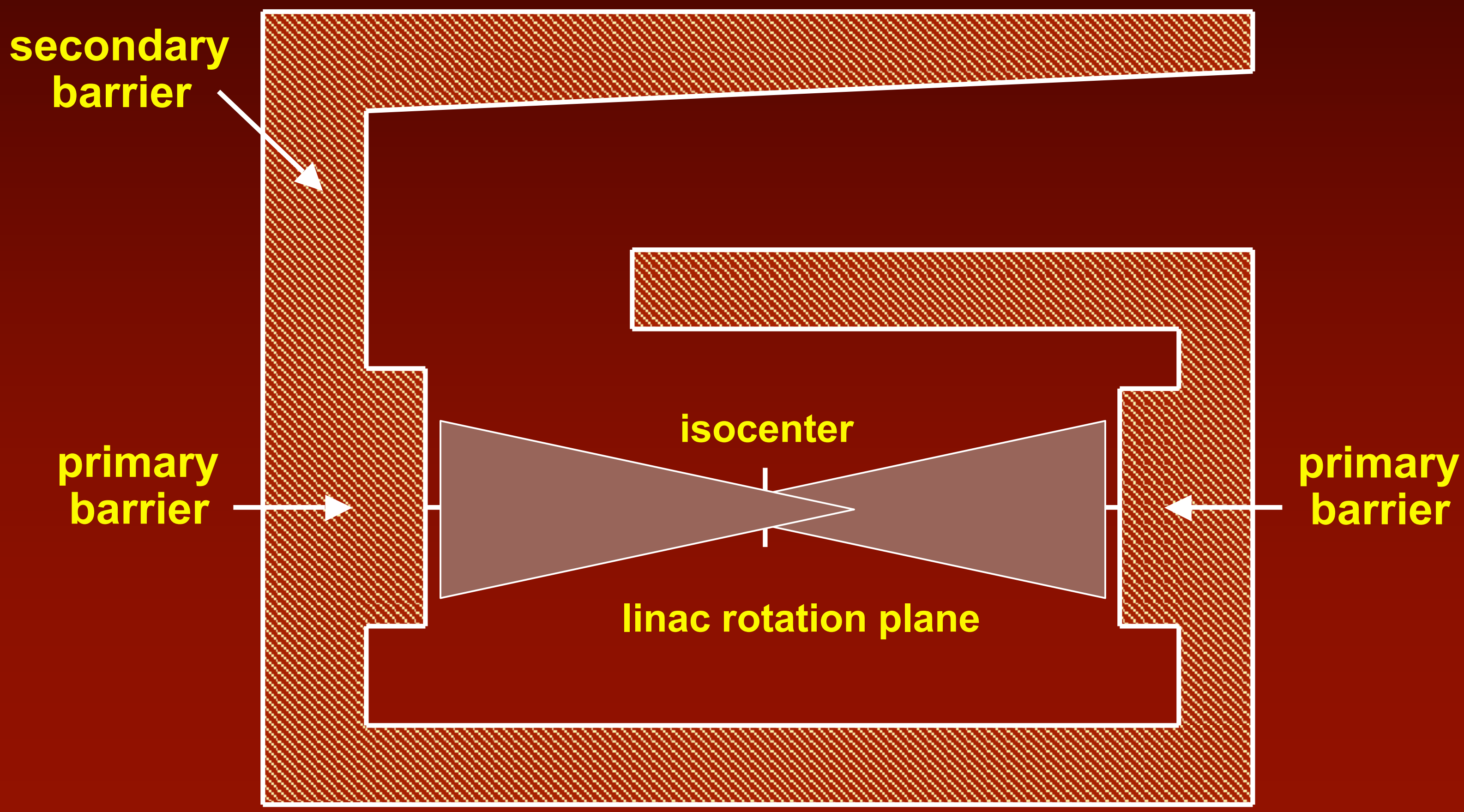
- Space availability
  - New facility
  - Retro-fit

- Future workload
- Capital funding

Types of Barriers

- Primary barriers
  - Attenuate primary (direct) beam
  - Very thick (1.5-2.5m)
- Secondary barriers
  - Leakage
  - Patient scatter
  - Wall scatter

Treatment Room



Reduction Factor B

- **B** is the factor by which the intensity of radiation (P_o) must be reduced to achieve the target dose rate **P**

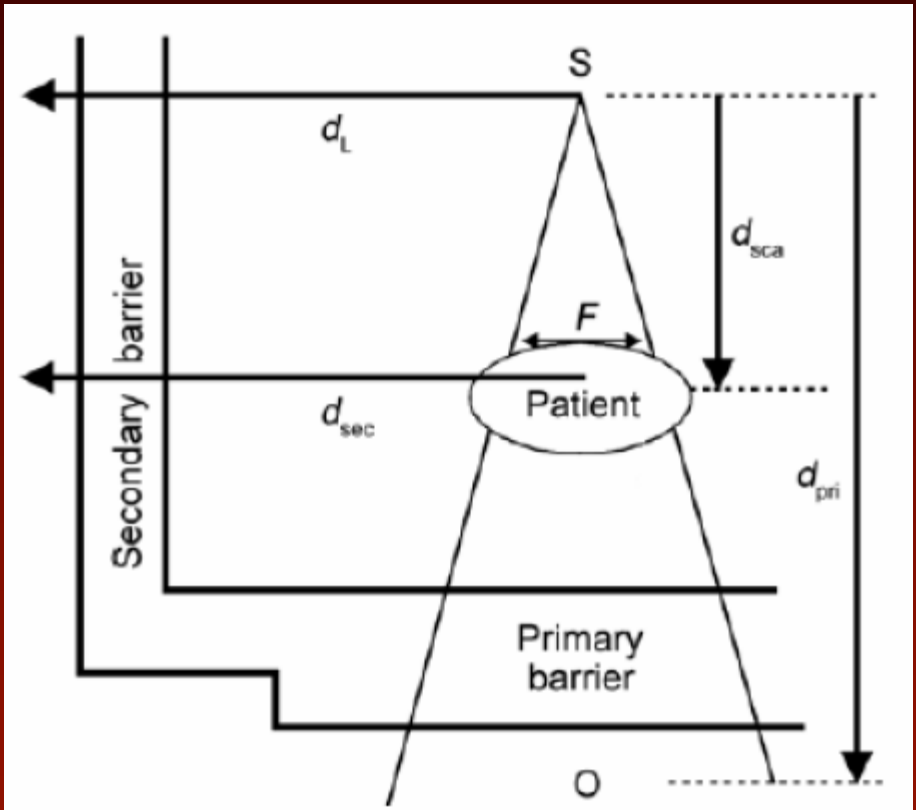
$$B = \frac{P}{P_o}$$

Reduction Factors

$$B_{\mathrm{L}} = \frac{P\, d_{\mathrm{L}}^2}{10^{-3}\, W\, T}$$

$$B_{\mathrm{ps}} = \frac{P}{aWT}\, d_{\mathrm{sca}}^2\, d_{\mathrm{sec}}^2\, \frac{400}{F}$$

$$B_{\mathrm{pri}} = \frac{P\, d_{\mathrm{pri}}^2}{WUT}$$



NCRP Report No. 151

NCRP Report No. 151

- The requied number (n) of TVLs is given by:
  - $N = -\log(B_{pri})$
- And for n > 1 the barrier thickness ($t_{barrier}$) is given by:
  - $t_{barrier} = TVL_1 + (n + 1)\ TVL_e$
- Where the first and equilibrium TVLs are used to account for the spectral changes as the radiation penetrates the barrier

Transmission Curves

- NCRP 49, 51
- B as a function of material thickness

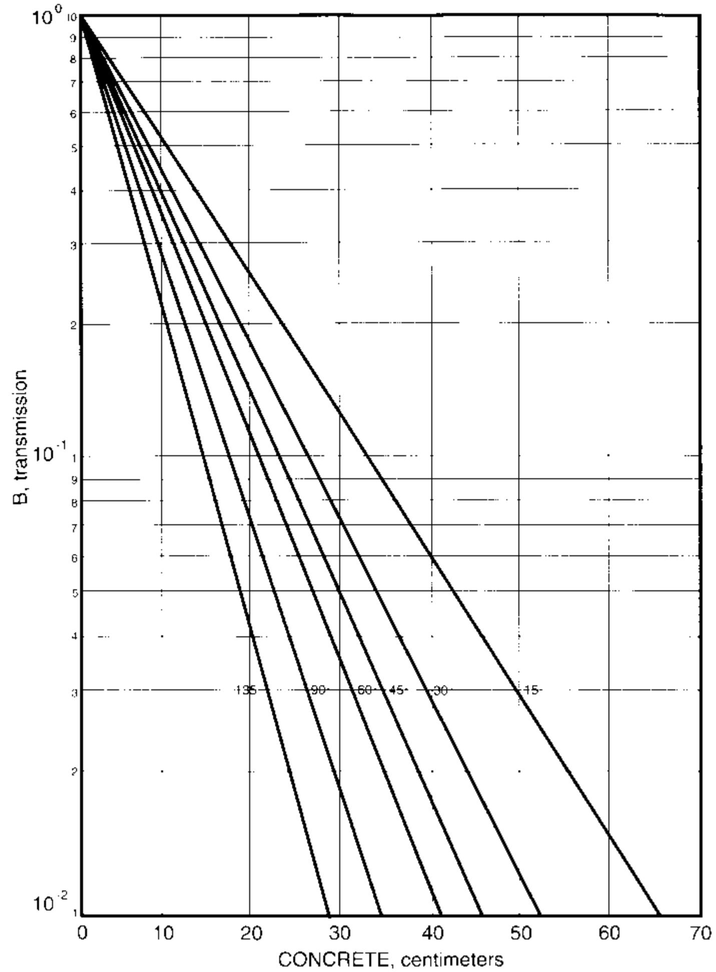


Figure 2-7. Transmission through concrete, density 2.35 g cm^{-3} (147 lb ft^{-3}), for 6 MV primary x-rays scattered at six different angles from a unit density phantom. From NCRP 1976 with permission.

Primary Barrier TVL - Materials

Energy	Material	TVL_1 (m)	TVL_e (m)
6 MV	concrete	0.370	0.330
	steel	0.100	0.100
	lead	0.057	0.057
10 MV	concrete	0.410	0.370
	steel	0.110	0.110
	lead	0.057	0.057
15 MV	concrete	0.440	0.410
	steel	0.110	0.110
	lead	0.057	0.057

*values from NCRP 151

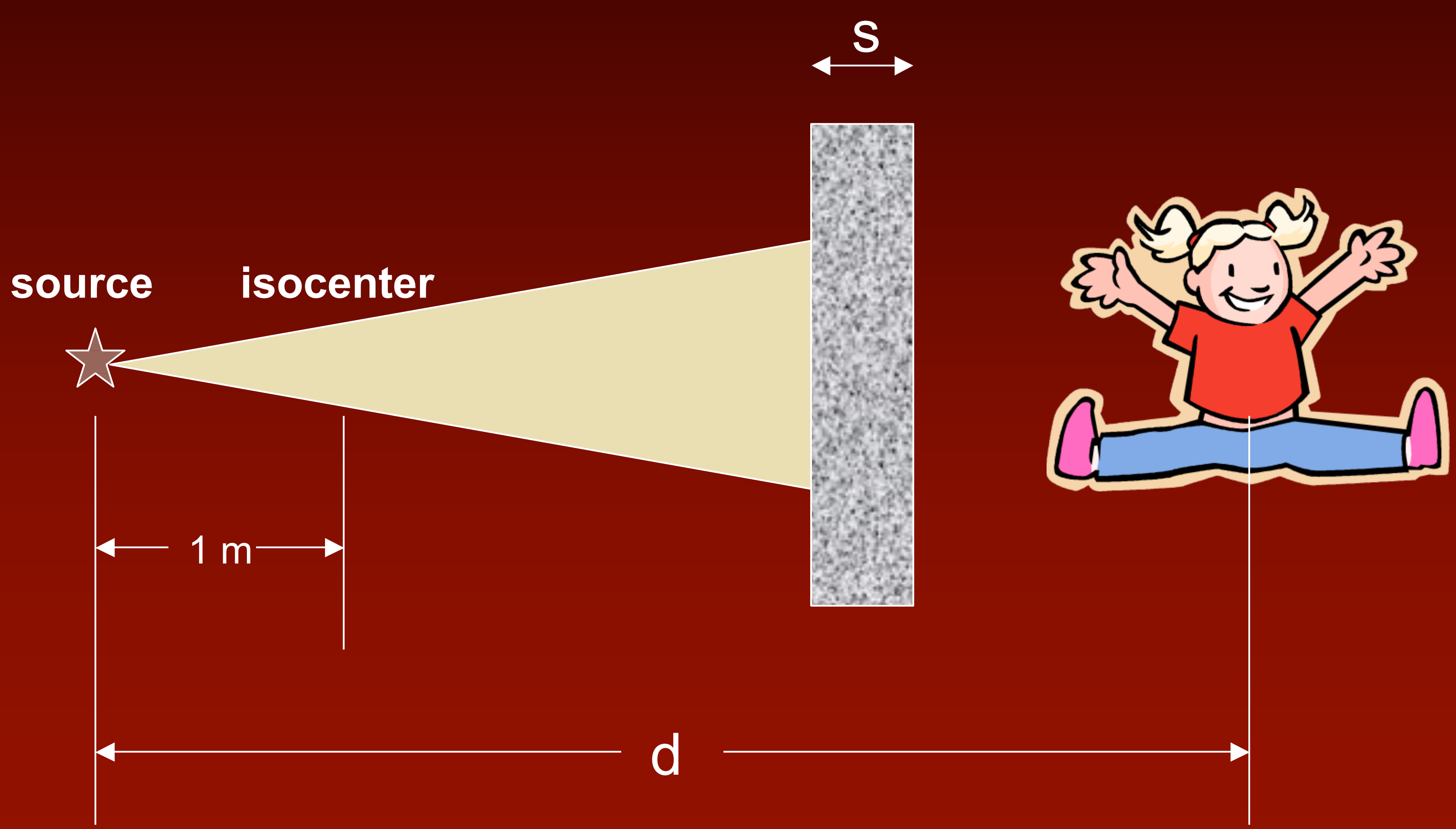
Rule of Thumb

- 6 TVL required for primary barrier
- 3 TVL required for secondary barrier

IDR, R_W, and R_h

- For each (primary barrier) location it is recommended to verify the following quantities are acceptable:
- R_W = Time-Average-Dose-Rate- in a week = IBR* W_{pri} *U / DR_{1m}
  - Where IDR = <u>transmitted</u> instantaneous does rate = DR_{1m} B/d^2
- → R_W x T should not be > P
- **For public areas** in Agreement States (NCR reg. → SSRs) regulations require an "in-any-one hour" constant. Evaluate with:
- R_h = Time-averaged dose in-any-one-hour
  - = $(m/40)R_W$ where 40 hours of operation per week applies and
    - M= ratio of maximum # of patients treatable in an hour to the average #
  - For example, Avg# = 30 pts/8 h, or W_{pri} $(D_{average})^{-1}$ $(40\text{ h wk})^{-1}$
- R_h should not be greater than 2 mrem or 20 μSv ("in-any-one-hour")

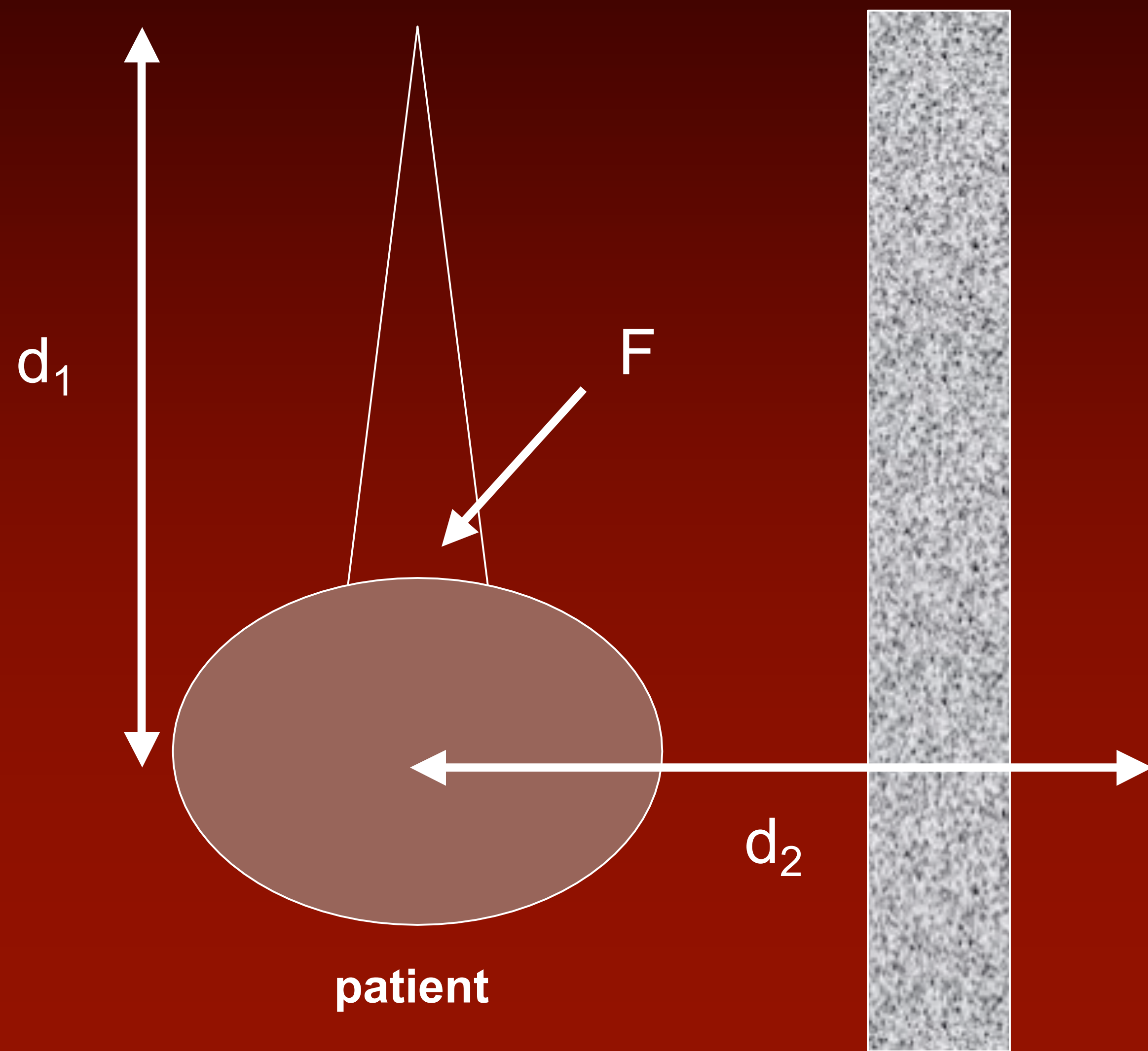
Basic Situation



Patient Scatter

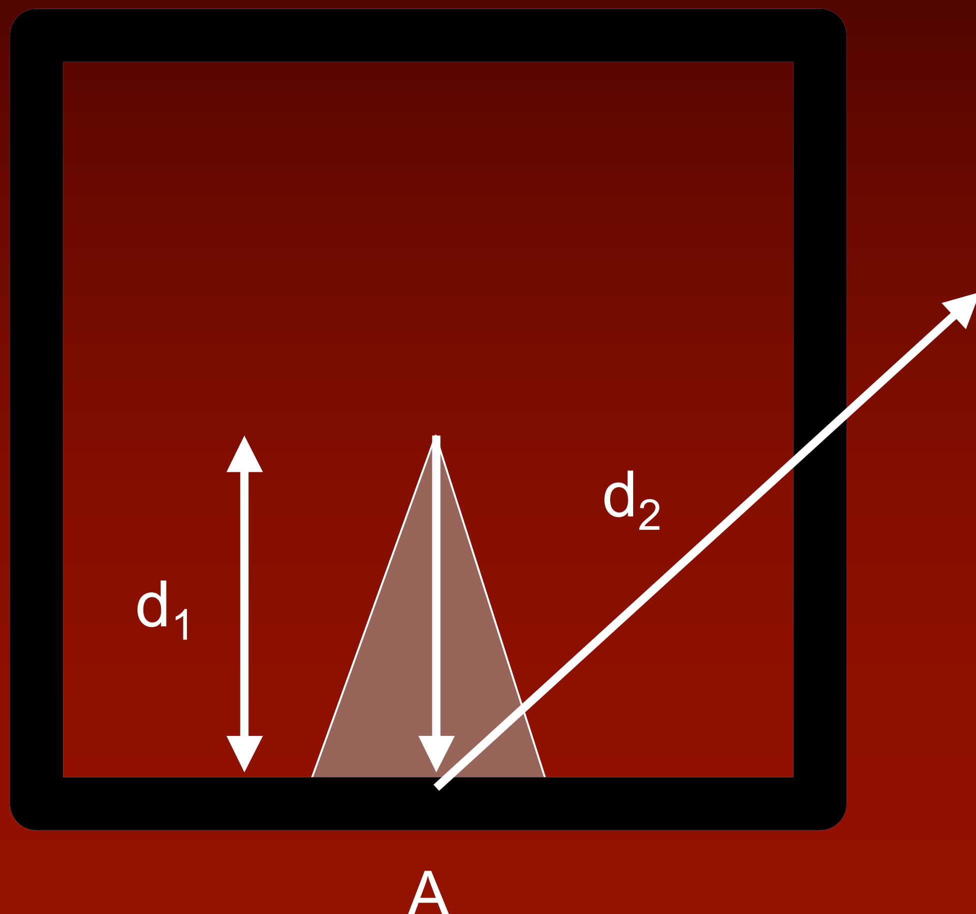
$$B = \frac{P\, d_1^2 d_2^2 \;\; 400}{a\, W\, T \;\;\; F}$$

F is the incident field size on the patient



Wall Scatter

$$B = \frac{P\, d_1^2 d_2^2}{\alpha\, A\, W\, T\, U}$$



# Typically shield to equal contribution of neutron dose at the entrance, 50 µSv each

- 1 TVL = 4.5 cm borated poly for mazed rooms
- 1 TVL = 8.5 cm borated poly for direct-shielded rooms
- Material is available in sheets of 2.54 cm thickness in USA
- Once the neutrons are dealt with, there is the photon dose from three sources to be handled
    - Direct leakage
    - Capture gamma radiation
    - Room and patient scatter

Neutron Fluence in NCRP 151, Table B.9

$$\Phi A = \frac{\beta Q_n}{4\pi d^2} + \frac{5.4\,\beta Q_n}{2\pi S_r} + \frac{1.3\,Q_n}{2\pi S_r}$$

- B = transmission through head
- Q_n = neutrons per Gy of x-rays
- S_r = total surface area of room
- 2π accounts for scattered and thermal neutrons entering maze

Kersey Method

- Varian 0.0004 Sv/Gy (at 1 m)
  - A “typical” maze length is about 6 m. Its heights is 3 m and width is 2 m
  - Area = 6 $m^2 = s_1$
  - A typical gap between the maze and far wall is 2.5 m and room height is also 3 m
  - Area = 7.5 $m^2 = S_0$
- Kersey’s formula gives the neutron dose at the door as the neutron dose at the isocenter x $(1/d_1)^2 \times (S_0/S_1) \times 10^{-(d2/5)}$

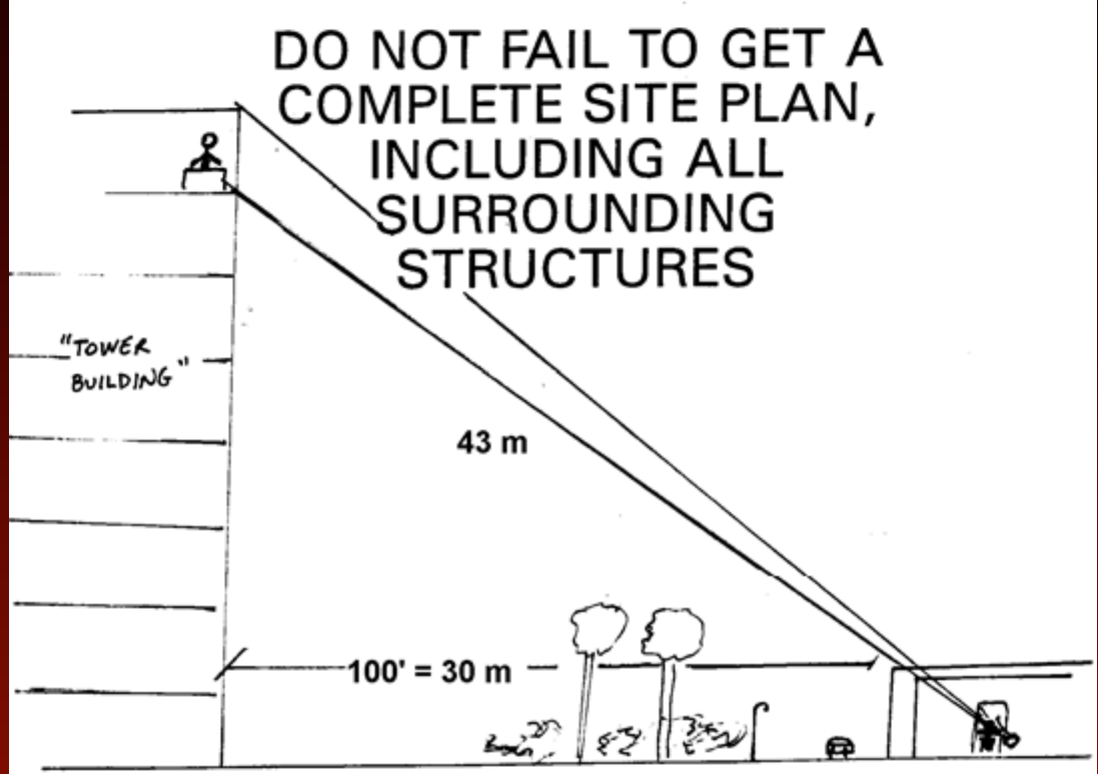
Photons at Door

- Leakage radiation is dominant component
- Capture gammas, room and patient scatter are also to be considered
- Direct leakage
  - Simple inverse square to door position
- Capture gammas
  - $h_{\varphi} = K\,\varphi_A\,10^{-(d_2/TVD)}$ where $d\text{-}_2 = 0$ (So, simply $K\,\varphi_A$)

- Room and patient scatter
  - Since scattering angle is $\sim 90^\circ$, energy is < 0.3 MeV, so it can be ignored

Required Information for Shielding Designs

- Architectural drawings of equipment layout in room
- Architectural drawings of surrounding areas indicating usage of these areas - offices, restrooms, corridor, exterior, etc.
- Elevation view of room or construction of floor and ceiling and distance between floors



Consider 4 patients a day receiving 100 cGy from a tangential field pointed as shown.

$$\frac{2{,}000\text{ cGy}}{(43)^2} = 1.08\text{ cGy to }20\ \mu\text{Gy requires }2.73\text{ TVL} = 36\text{'' concrete (6mv)}$$

Workload Questionaire

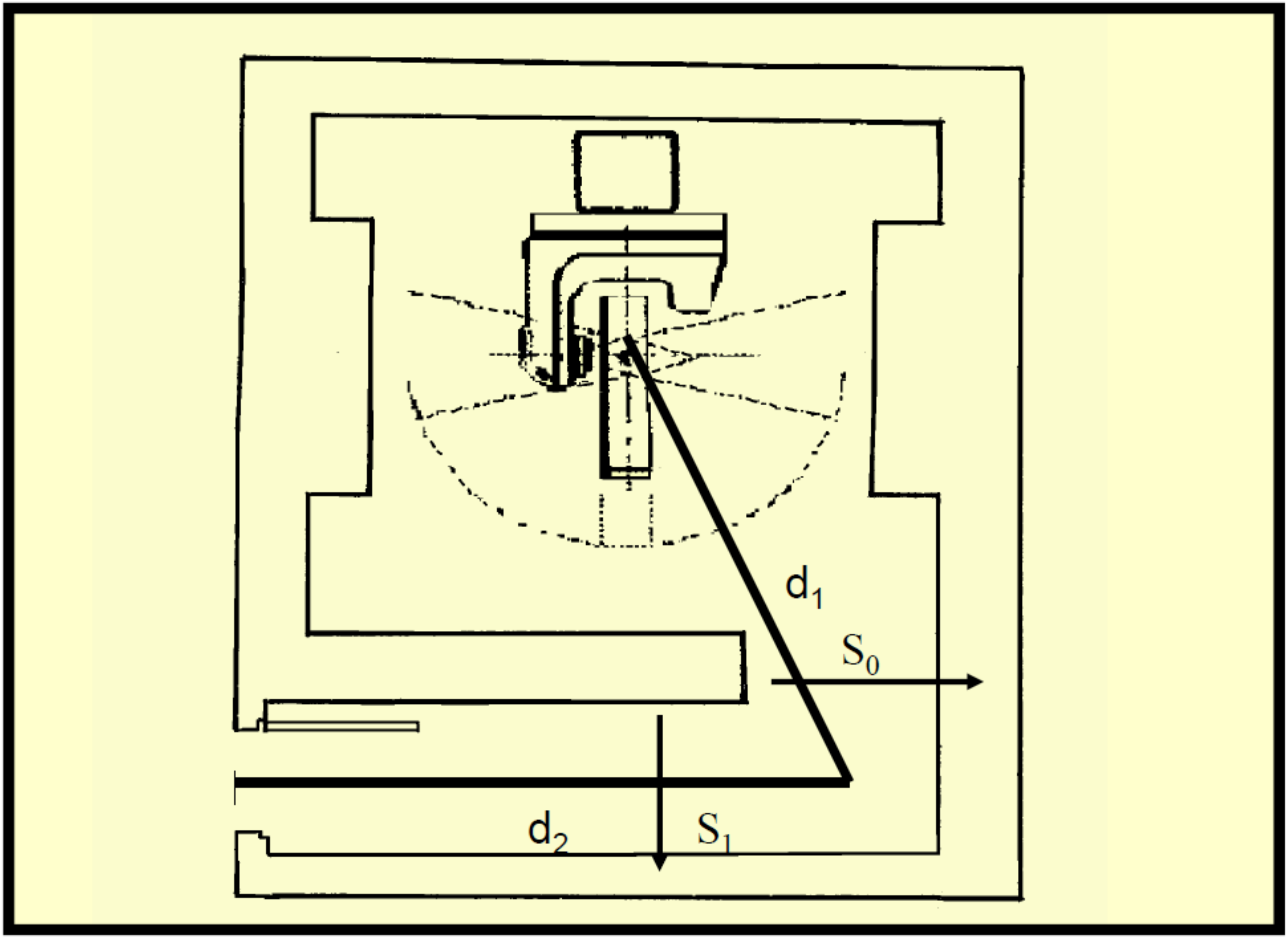
1) Make and model of accelerator: Varian Tru Beam
2) MV of X-ray beams: 6 MV, 10 MV 15 MV
3) MV of FFF beam(s): 6 MV 10 MV
4) Number of patients per day: 35
5) Number of patients per day treated with conventional method and tumor dose : 25/180 cGy
5: 15 MV
8: 10 MV
12: 6 MV
6) Number of patients treated per day with IMRT and tumor dose and MU/cGy: 10/180 cGy/ F=5
7) Fraction of IMRT patients treated with the high energy beam:
1: 15 MV
3: 10 MV
6: 6 MV
8) Number of SBRT patients per week, number of fractions per patient, tumor dose per fraction, MU/cGy, MV to be used: 2: 5: 10 Gy.: F=5, 10 MV.
9) Number of SRS patients per week, number of fractions per patient, tumor dose, MU/cGy, MV to be used: 0:1:24 Gy: F=3; 6 MV. (N/A) There are no SRS patients projected to be treated at this site.
10) Other treatment methods SRT, total body etc. For each mode indicate number of patients per day, number of fractions, tumor dose per fraction, MU/cGy, MV to be used **N/A**

Workload Assuumptions for Dual Energy Linear Accelerators

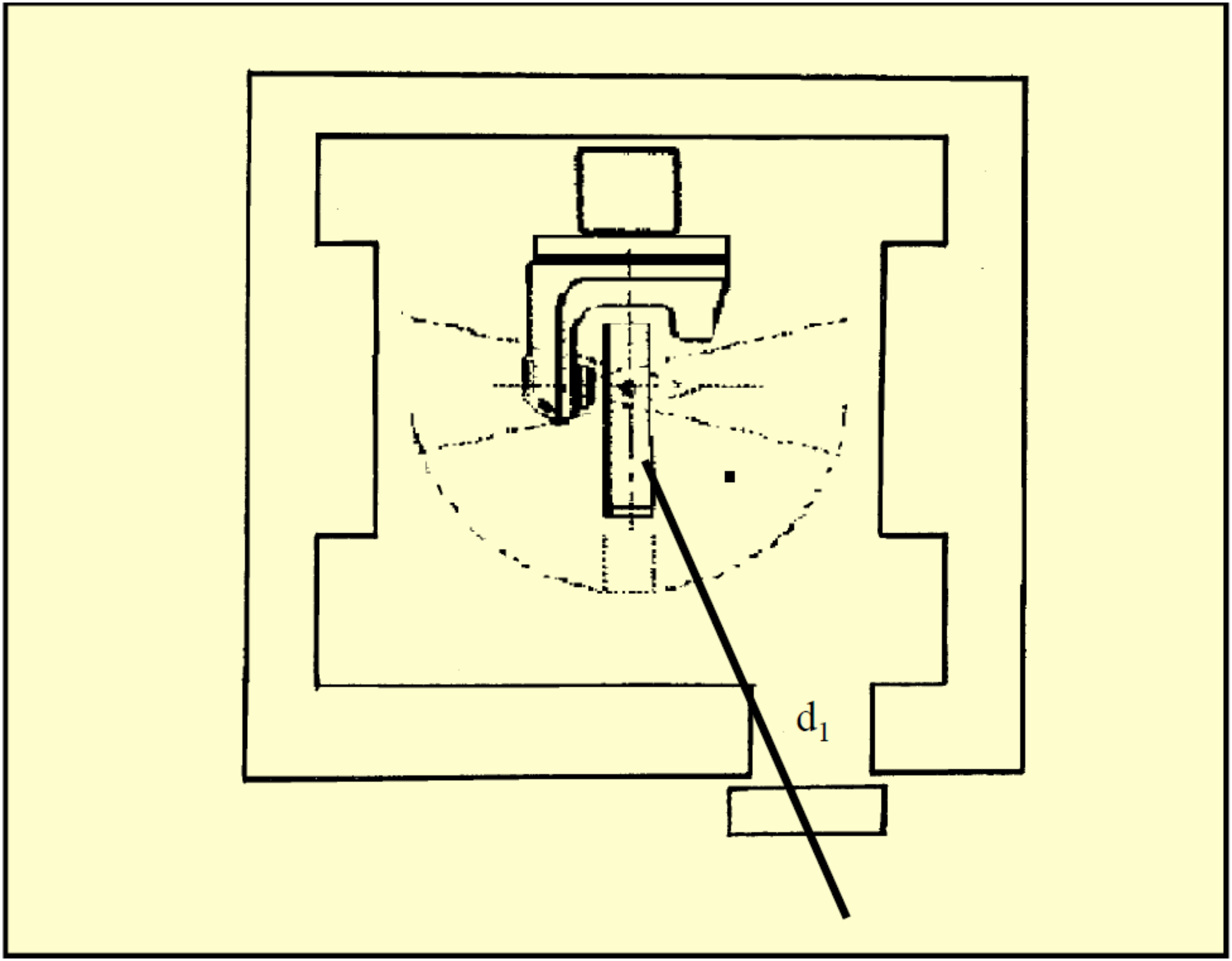
- Preferable to assume full 450 Gy/wk workload is at the higher energy
  - Simpler, more conservative calculation
  - Appropriate for new construction
- For existing construction, dual-energy calculation may be appropriate
  - If modifications to existing vault are difficult and size constrained
  - Split 30 patient workload to ensure at least 250 Gy/wk at higher MV
    - With 17 patients, 255 Gy/wk at higher MV

Mode	Gy/wkpatient	Patients/day	W (Gy/wk)
Single x-ray mode	15	30	450
Dual x-ray mode	15	30	450

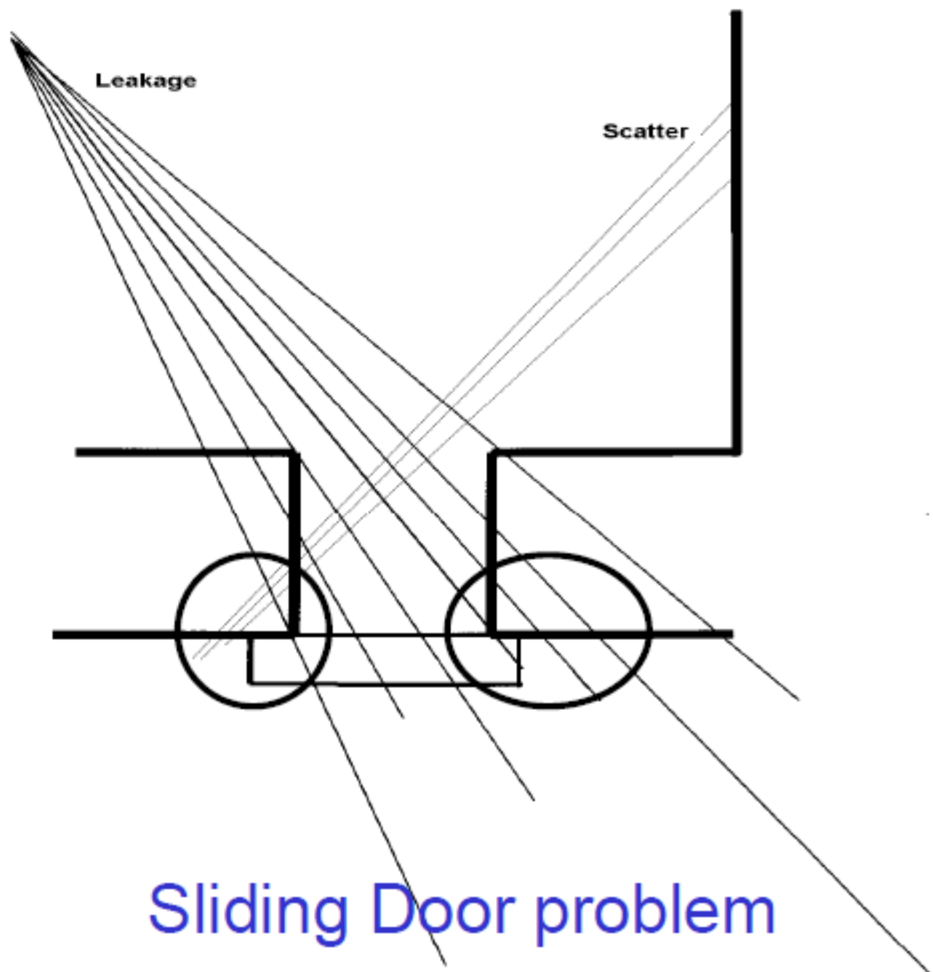
At least 250 Gy/wk at high MV mode



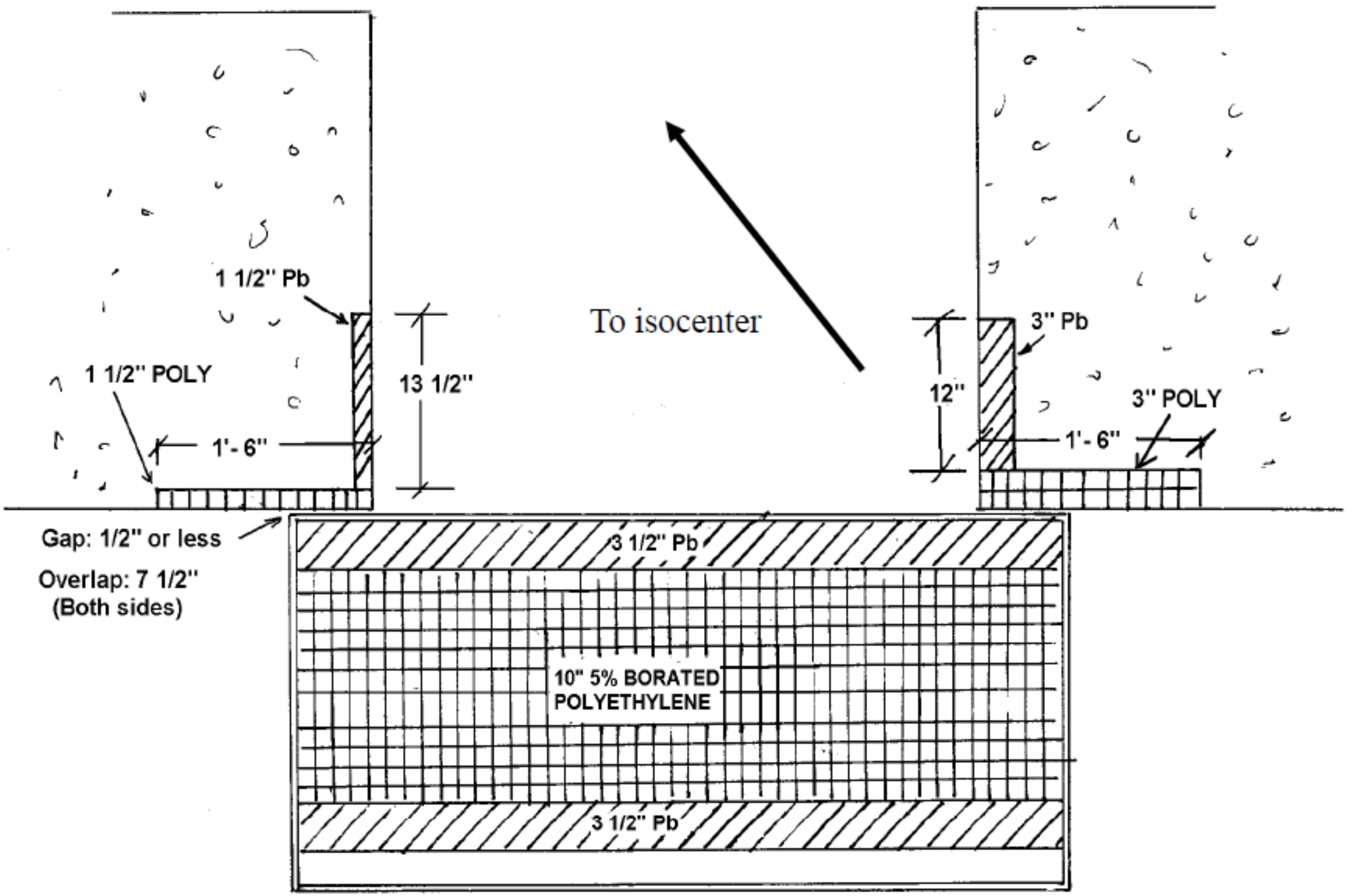
d1
S0
d2
S1



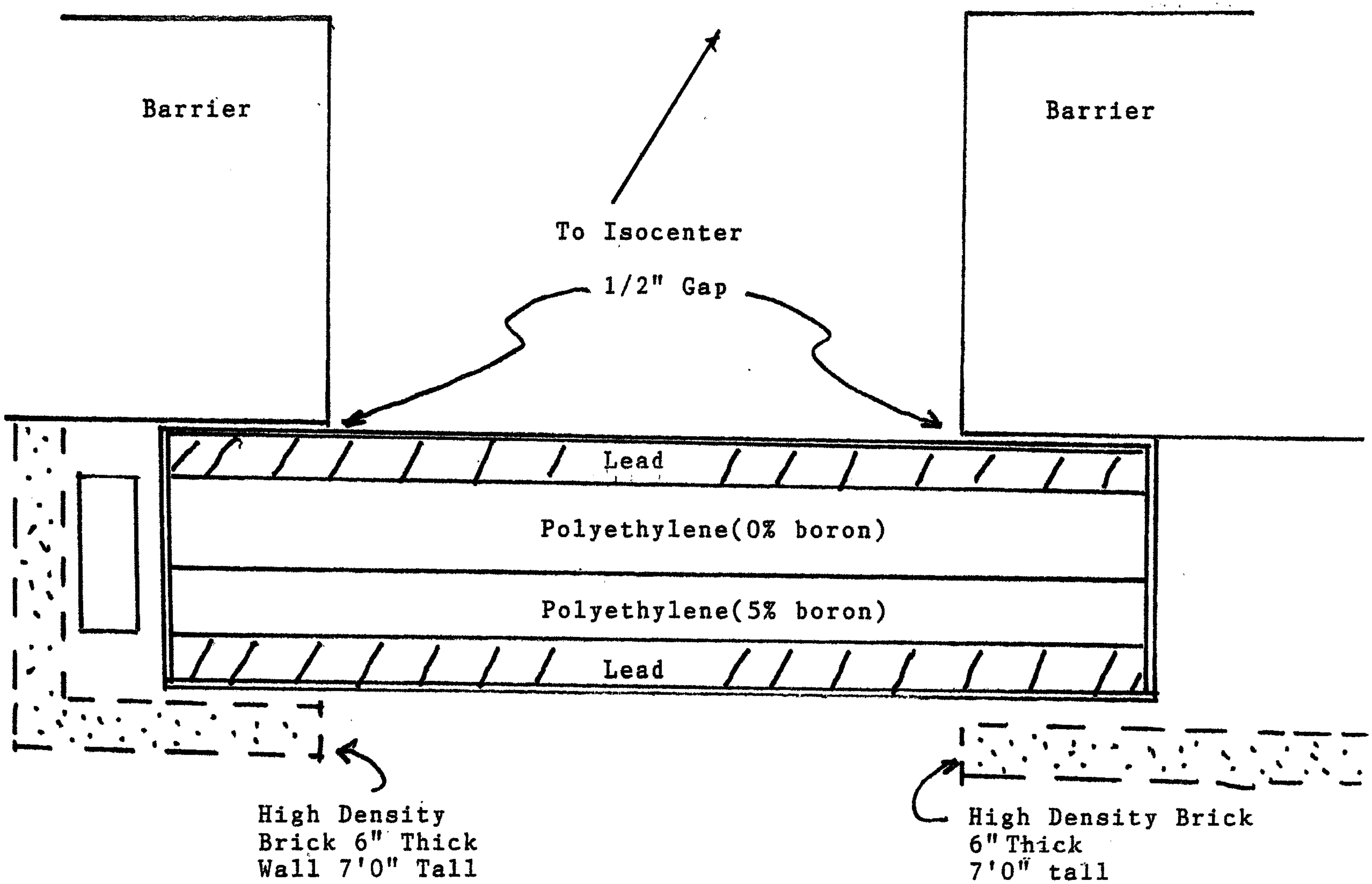
d_1

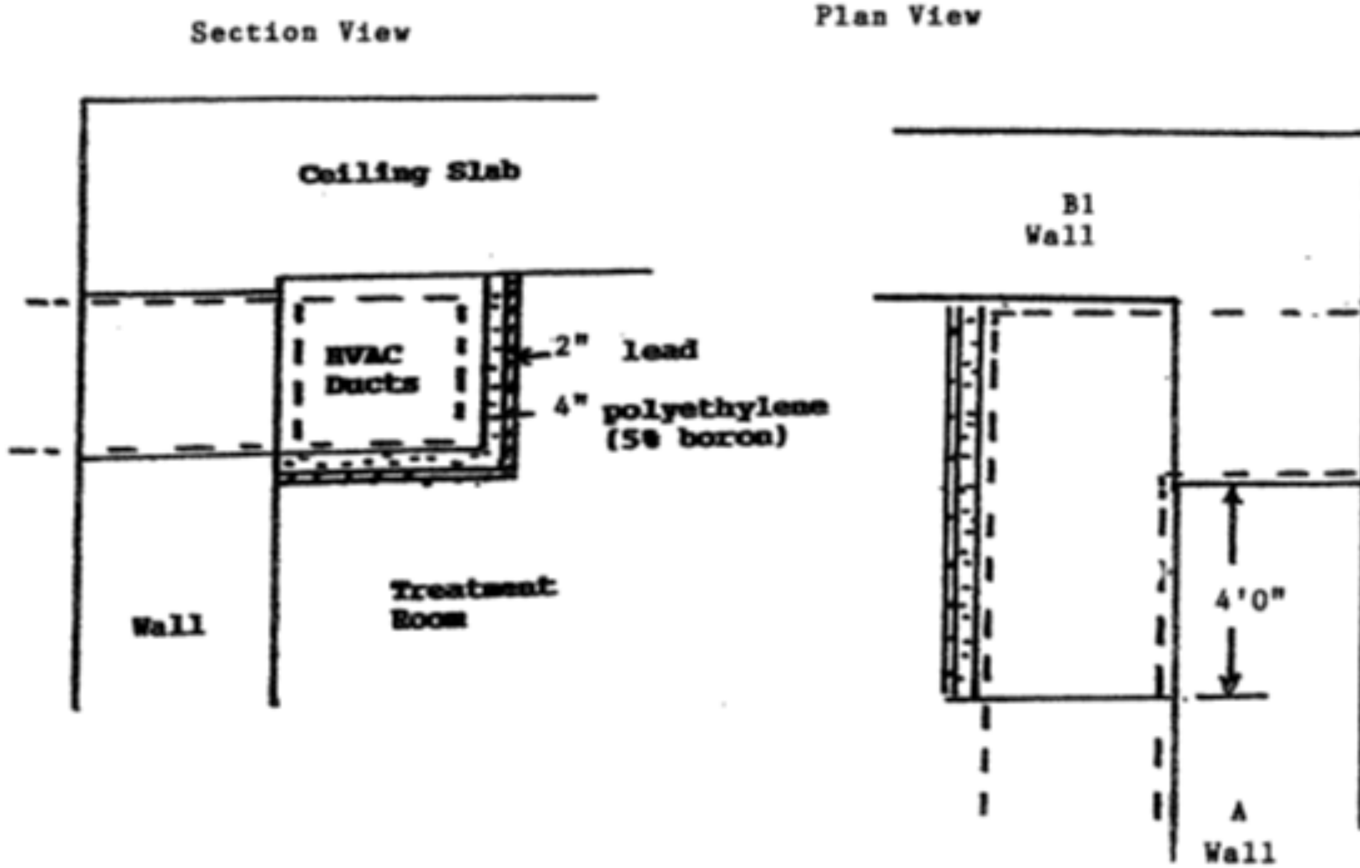


Sliding Door problem



Door Detail Vault #1


Barrier
Barrier
To Isocenter
1/2" Gap
Lead
Polyethylene(0% boron)
Polyethylene(5% boron)
Lead
High Density
Brick 6" Thick
Wall 7'0" Tall
High Density Brick
6" Thick
7'0" tall

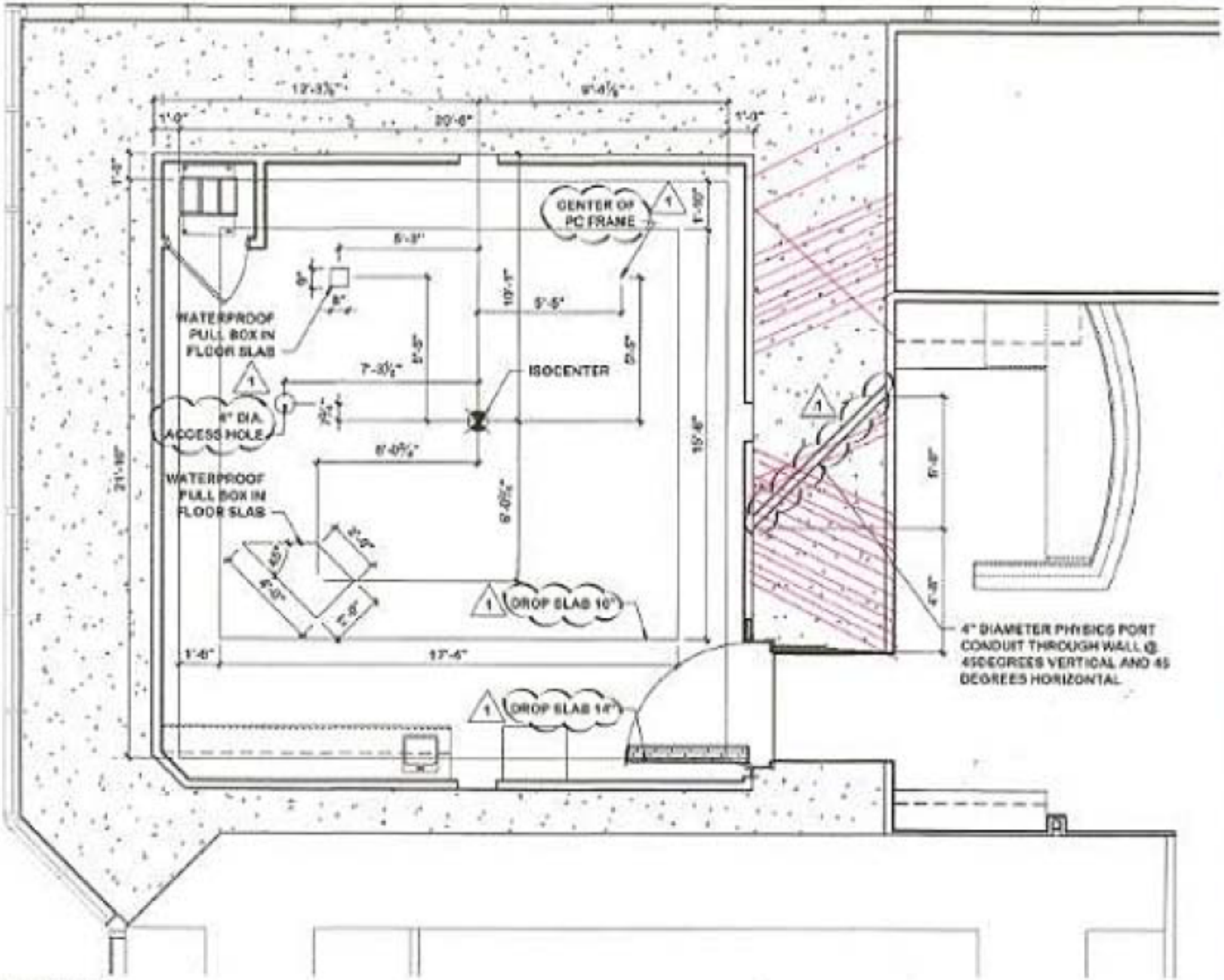


Section View
Plan View
Ceiling Slab
HVAC
Ducts
2" lead
4" polyethylene
(5% boron)
Wall
Treatment
Room
B1
Wall
4'0"
A
Wall

Cyberknife (CK) VCI Planning Guide

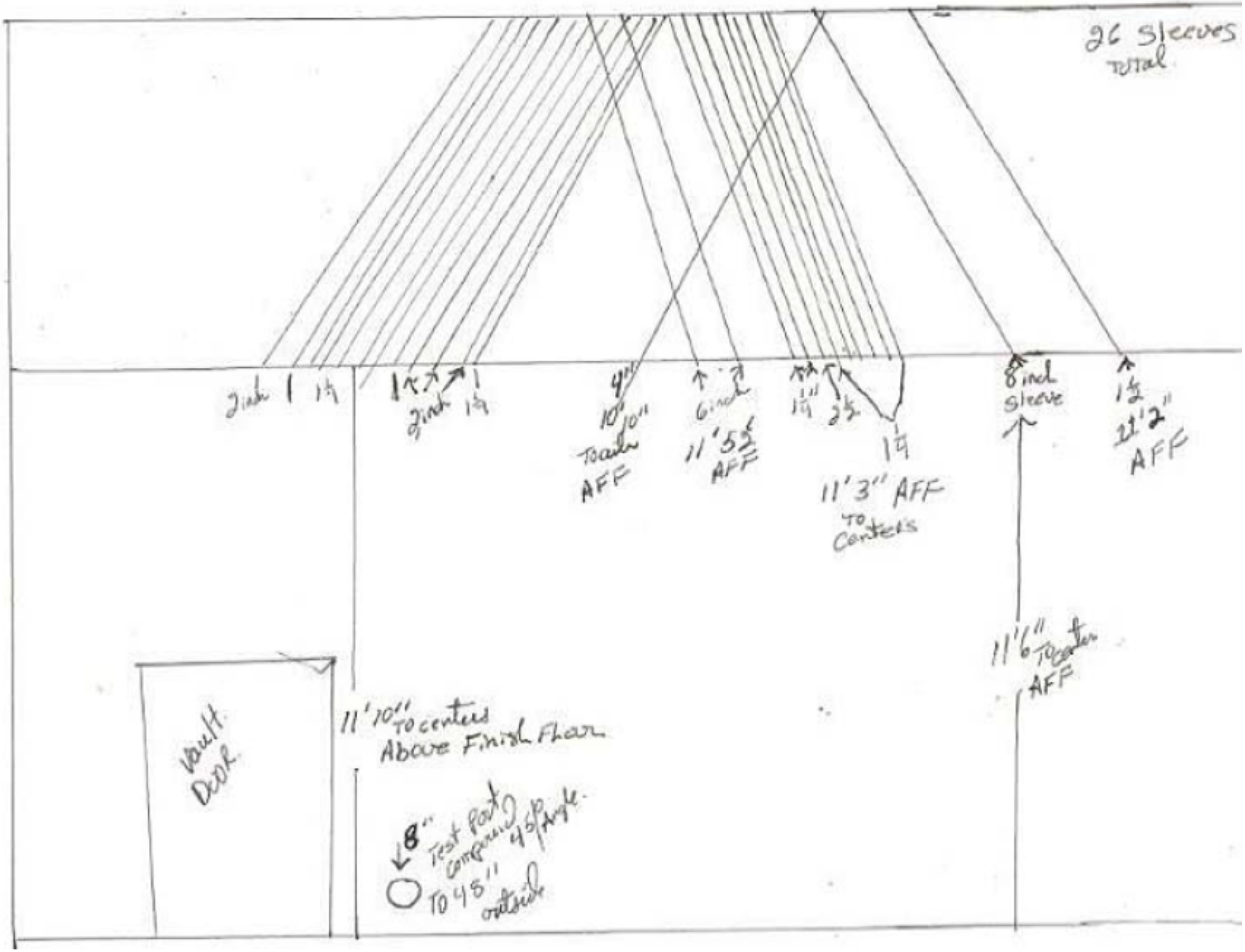
- Table 4: Workload Estimations
  - Brain 45 minutes 7.45 Gy @ 80 cm SAD
  - Spine/Body 60 minutes 11 Gy @ 100 cm SAD
- Instantaneous Dose Rate (IDR)
  - A worst case scenario for the control area and the door were communicated as: Control Area: 13.4 mR/hr

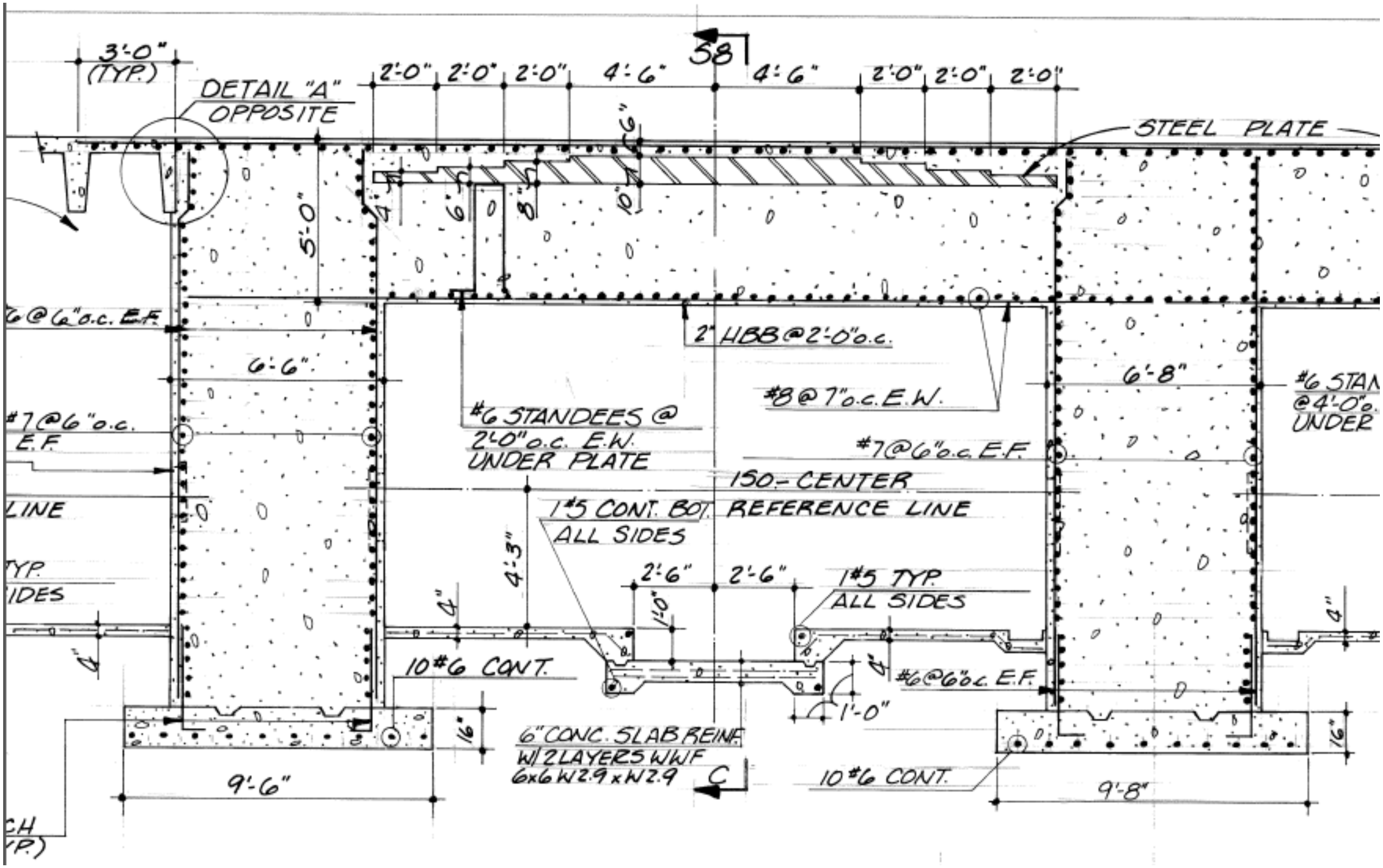
- Exposure Conditions
- 13.4 mR/hr IDR
- SAD of 65 cm
- 6 cm cone
- 800 MU/min rep rate
- IDR of 13.4 mR/hr
- 0.223 mR/min
- Limit = 2 mR in any one hour
- = 8.9 minutes in any 1 hour period of time
- = 7164 MU delivered by 1 beam orientation to meet the ALAR A condition
- Calibration Conditon 1 cGy= 1MU
- 7164 cGy in 1 hour with beam located a 1 position
- 12 Gy per Tx fraction
- 6 patient Tx in any one hour
- This is not a realizable clinical treatment scenario



1 VAULT PLAN

1/4" = 1'-0"

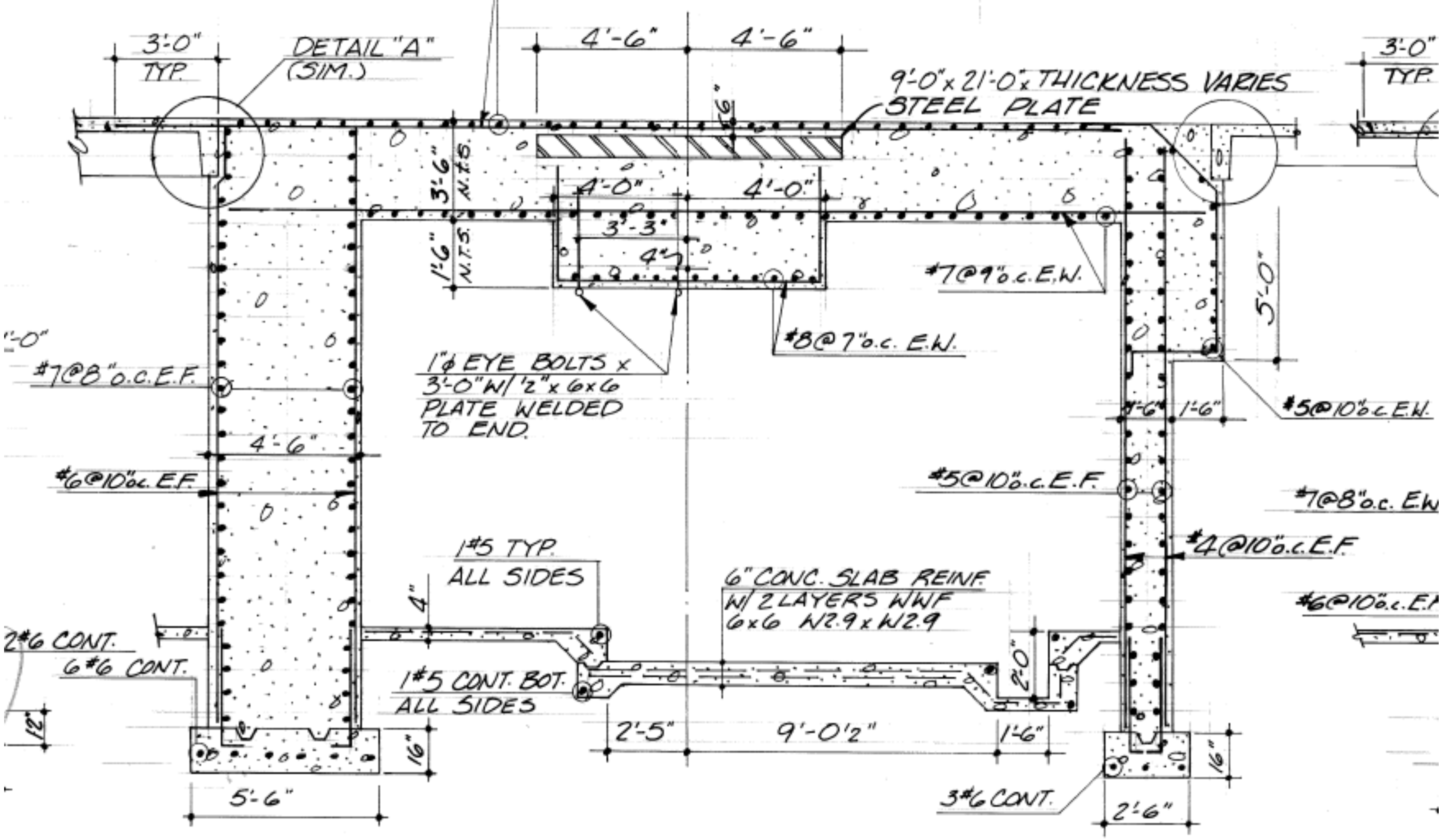

26 Sleeves
total
2 inch
1
1¼
2 inch
1¼
4"
10'10"
To center
AFF
6 inch
11'5½
AFF
1¼"
2½
1¼
11'3" AFF
To
Centers
8 inch
sleeve
1½
11'2"
AFF
11'6" To center
AFF
Vault
Door
11'10" To centers
Above Finish Floor
8" Test Port
compound 45 angle.
To 48" outside



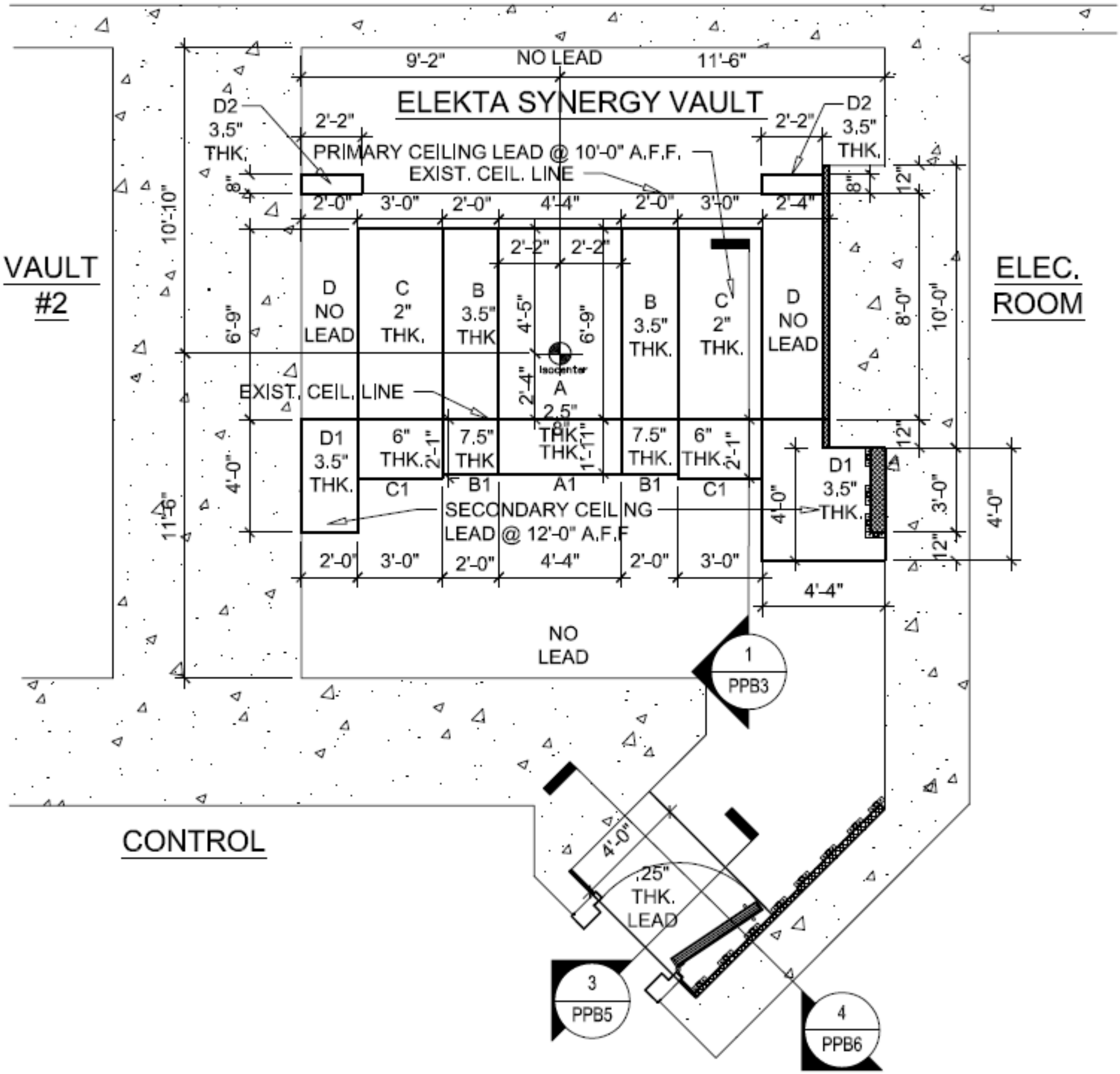
3'-0" (TYP.)
DETAIL "A" OPPOSITE
2'-0" 2'-0" 2'-0" 4'-6" 4'-6" 2'-0" 2'-0" 2'-0"
58
STEEL PLATE
5'-0"
6'
8"
10"
6"
6@6"o.c. E.F.
2" HBB@2'-0"o.c.
6'-6"
6'-8"
#8@7"o.c.E.W.
#6 STANDEES @ 2'-0"o.c. E.W. UNDER PLATE
#6 STAN @4'-0"o. UNDER
#7@6"o.c. E.F.
#7@6"o.c.E.F.
150-CENTER REFERENCE LINE
LINE
1#5 CONT. BOT. ALL SIDES
4'-3"
2'-6" 2'-6"
1#5 TYP. ALL SIDES
TYP. IDES
1'-0"
4"
10#6 CONT.
#6@6"o.c. E.F.
1'-0"
16"
6"CONC. SLAB REINF. W/2LAYERS WWF 6x6 W2.9 x W2.9
C
10#6 CONT.
9'-6"
9'-8"
CH (YP.)

SECTION S8-A
SCALE: 1/4" = 1'-0"

NOTE: PROVIDE CONC. ACCESSORI
STANDEES TO SUPPORT RE
AND STEEL PLATES AS
RECOMMENDATIONS AND

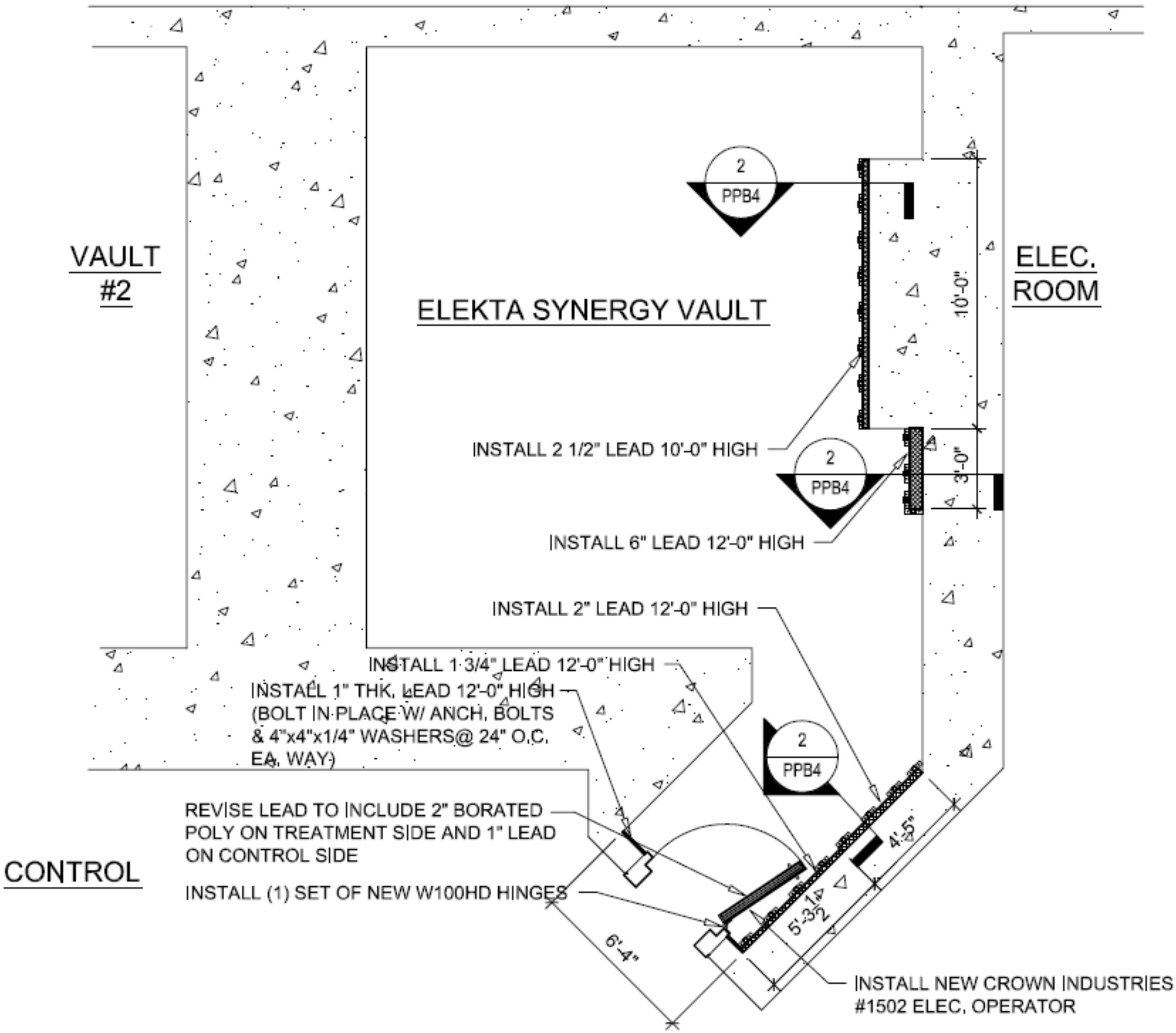


SECTION S8-C
SCALE: 1/4" = 1'-0"



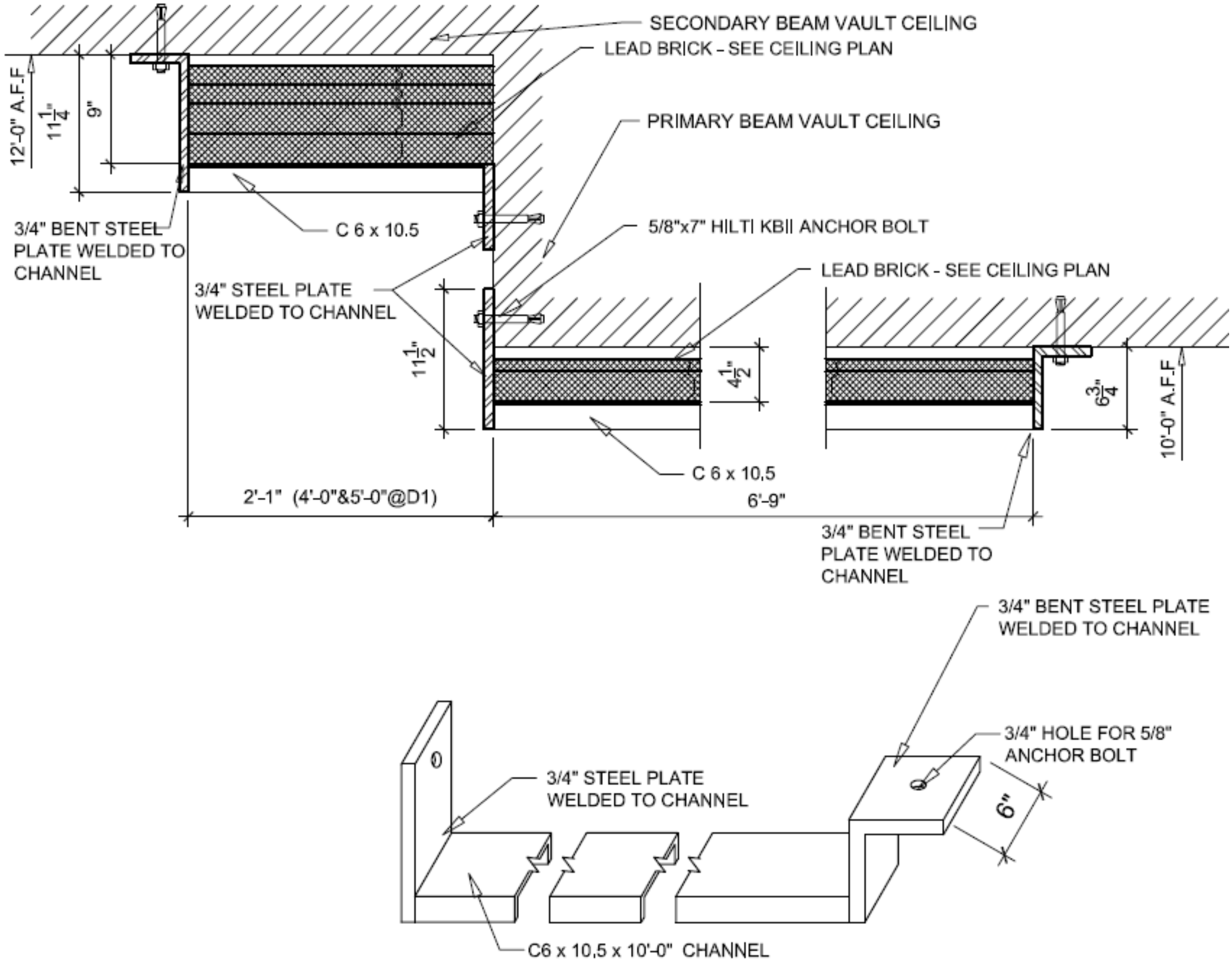
ELEKTA SYNERGY VAULT CEILING PLAN

SCALE: 3/16" = 1'-0"



ELEKTA SYNERGY VAULT FLOOR PLAN

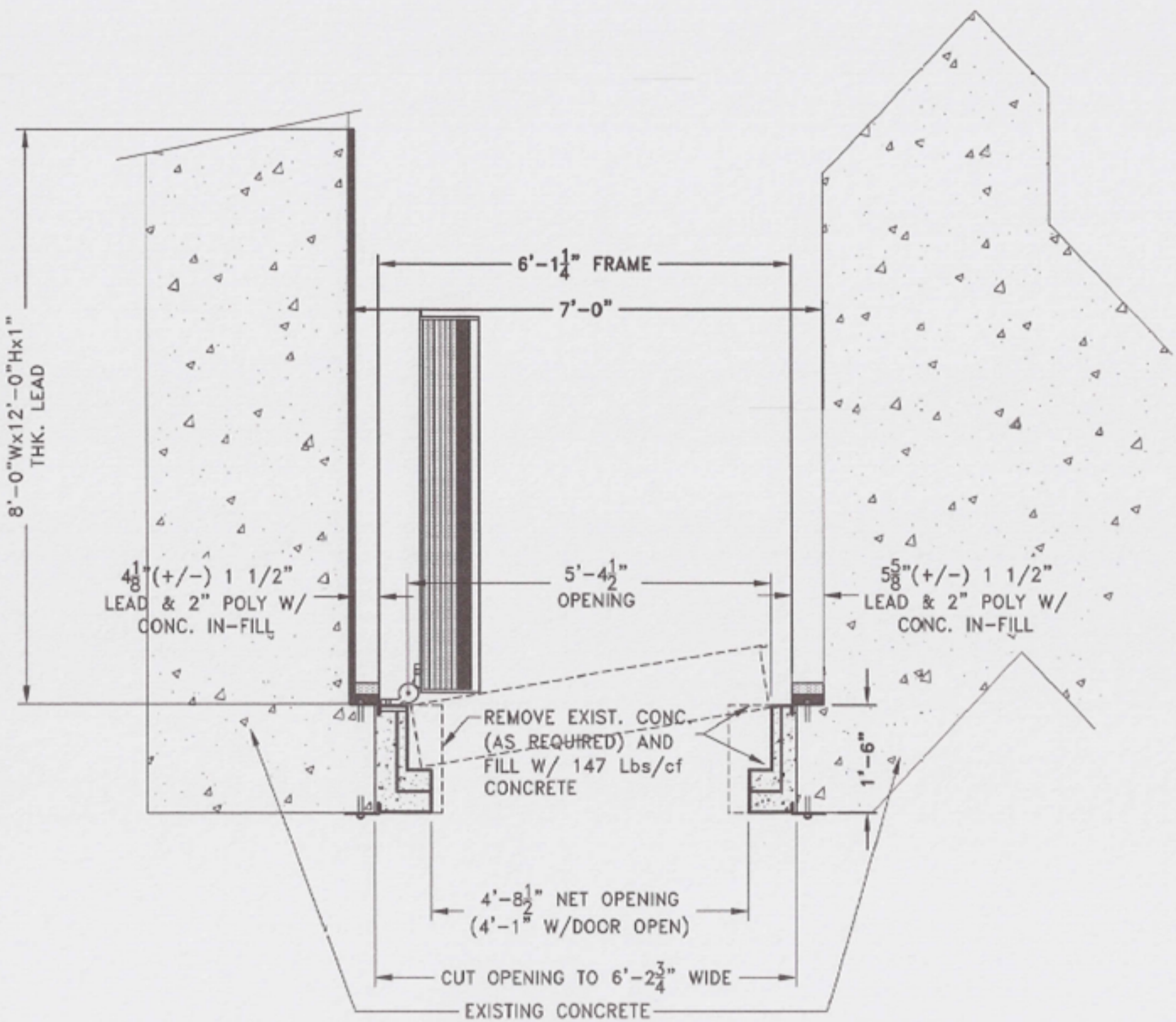
SCALE: 3/16" = 1'-0"



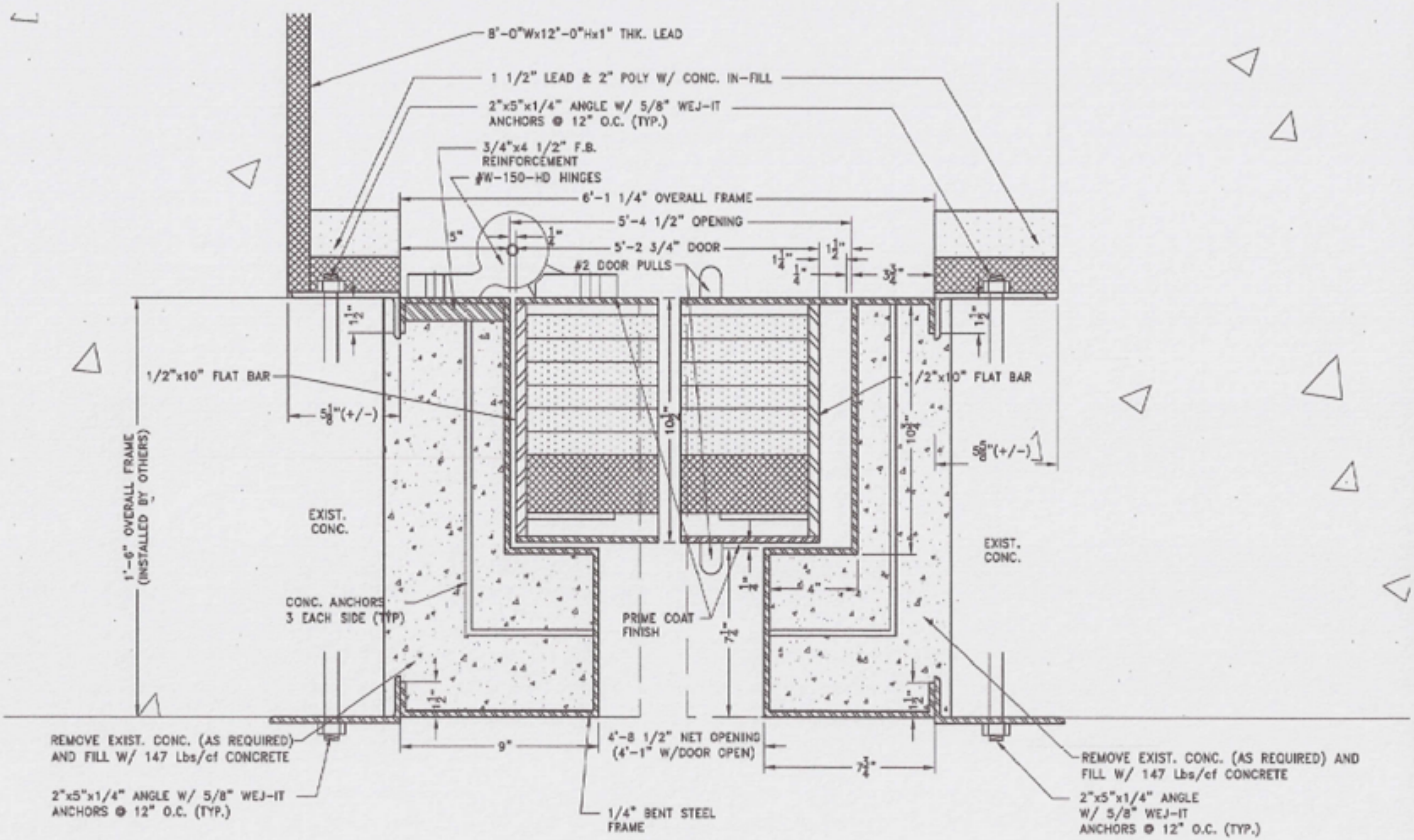
1
PPB3

CEILING LEAD SUPPORT

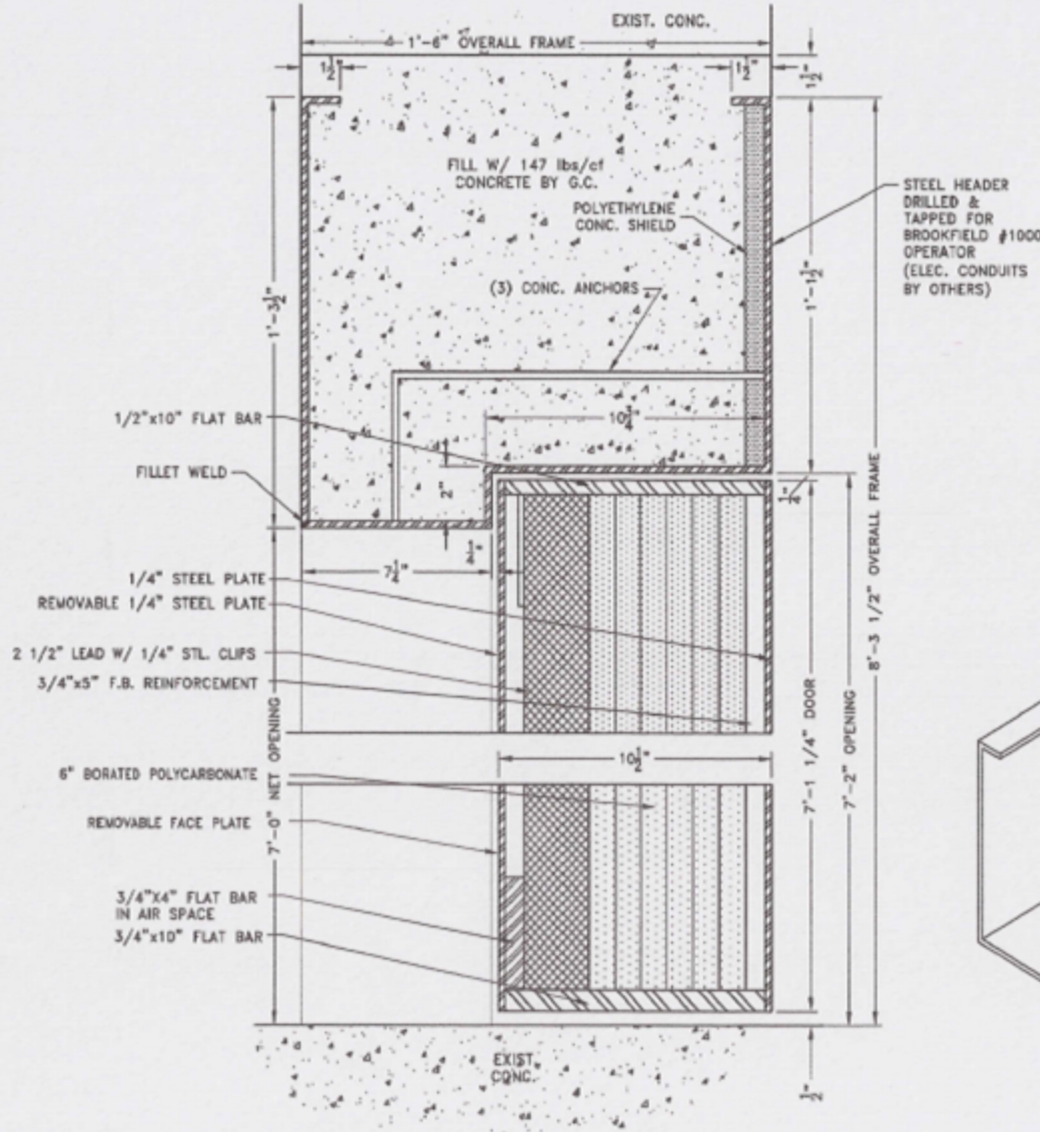
SCALE: 1" = 1'-0"



DOOR PLAN DETAIL

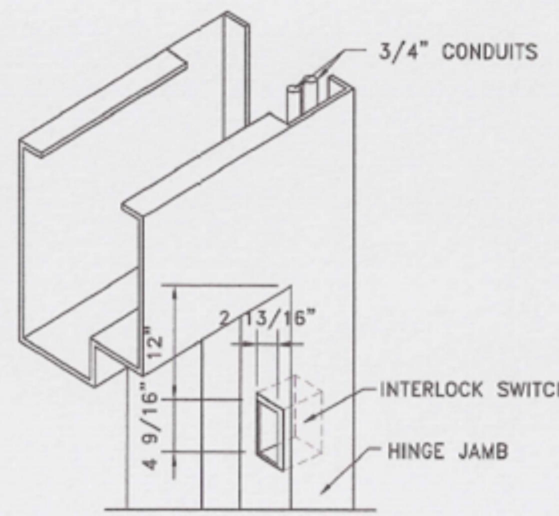


JAMB SECTION



HEAD & SILL SECTION

& NEUTRON DOOR



INTERLOCK SWITCH LOCATION
LEFT HAND

CDH PARTNERS INC.

This document has been reviewed for conformance with the design concept and general compliance with the contract documents. The contractor is responsible for confirming and correlating all quantities and dimensions, fabrication and construction methods, and coordinating this work with all other trades.

- [x] No exceptions taken
- [ ] Resubmit
- [ ] Exceptions noted
- [ ] Reject

Date: 6-26-2013 By: JDM

This approval is conditional to Randall Miller's acceptance