AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

Advancing the Science, Education & Professional Practice of Medical Physics

SHIELDING TECHNIQUES FOR CURRENT RADIATION THERAPY MODALITIES

MELISSA C. MARTIN, M.S., FACR, FAAPM

PRESIDENT AAPM - 2017

PRESIDENT - THERAPY PHYSICS INC., GARDENA, CA

MELISSA@THERAPYPHYSICS.COM

AAPM Spring Clinical Meeting - March 18-21, 2017

New Orleans, LA

DISCLOSURES

None

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE
Advancing the Science, Education & Professional Practice of Medical Physics

International Organization for Standardization (ISO) Technical Committee 85
Subcommittee 2
Working Group 23 - 2015
Meeting in Boras, Sweden

Produced ISO Standard 1664: 2015

Radiological Protection - Medical Electron Accelerators- Requirements and Recommendations for Shielding Design and Evaluation

MAJOR REFERENCES FOR ISO 1664

- **NCRP 151: *Structural Shielding Design and Evaluation for Megavoltage X-ray and Gamma Ray Radiotherapy Facilities (2005)***
- **Germany, Denmark, and France Radiation Control Regulations**

EQUIPMENT CURRENTLY AVAILABLE

Linacs: Varian or Elekta

Tomotherapy

Cyberknife

ViewRay

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE
Advancing the Science, Education & Professional Practice of Medical Physics

VARIAN TRUEBEAM™ MULTI-ENERGY LINAC

NEW TECHNIQUES IN RADIOTHERAPY

- Modulation of Beam Intensity
- Modulation of the Dose Rate
- Arc therapy

INTENSITY MODULATED RADIATION THERAPY (IMRT)

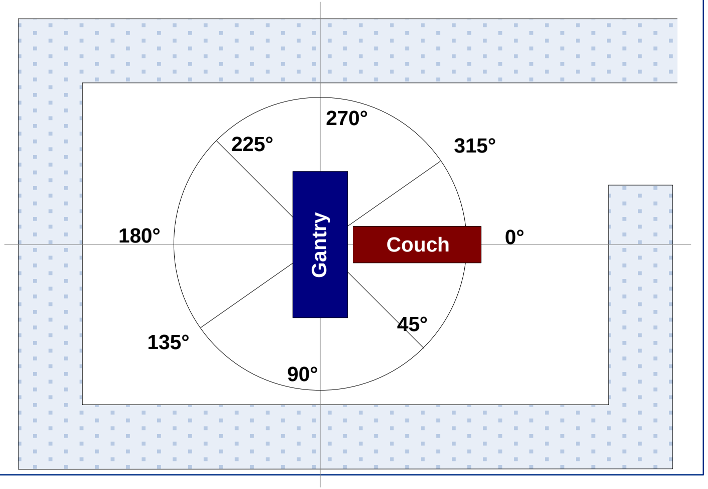
- IMRT requires increased monitor units per cGy at isocenter
  - IMRT ratio is the ratio of MU with IMRT per cGy at isocenter
- Percent workload with IMRT impacts shielding
  - 50% typically assumed; 100% if vault is dedicated to IMRT
- Account for IMRT by multiplying workload by IMRT factor
  - IMRT Factor = % IMRT x IMRT ratio + (1 - % IMRT)
- Leakage Workload: $W_L = W \times$ IMRT Factor
  - W_L replaces W in leakage unshielded dose calculation with IMRT

TomoTherapy®

- **Helical Modulated Radiotherapy**

TomoTherapy®

- Delivers IMRT with beam geometry resembling diagnostic CT
  - 6 MV slit beam of radiation continuously rotates around patient
  - Patient continuously moves through the beam
  - On-board primary beam block



TomoTherapy®

- **Shielding design is based on fraction of workload at isocenter**
- **Average primary radiation (90/270 degree direction) less than 3% of average leakage and scatter**
- **Leakage plus clinically relevant scatter (normalized to 1 m from isocenter) is less than 0.02% of workload at isocenter**
- **Similar to conventional linear accelerator leakage fraction**
- **Use NCRP 151 recommended 0.1% leakage fraction for shielding calculations (for combined leakage, scatter & primary)**
- **Consistent with NCRP Statement 10 guidance**

TomoTherapy®

- TomoTherapy® treatment fractions are similar to those of conventional gantry linear accelerator
- 3 Gy absorbed dose per treatment conventional fraction
- Larger treatment fraction for SRS & SBRT
- Dose is at isocenter (85 cm from target for TomoTherapy®)
- Leakage fraction is normalized to workload at isocenter
- Use 16 MU/cGy to calculate leakage workload
- Leakage fraction is normalized to workload at isocenter

*SRS=stereotactic radiosurgery; SBRT=stereotactic body radiation therapy

CyberKnife®

Robotic Arm Accelerators

CyberKnife®

- CyberKnife® uses small 6 MV linac with a robotic arm
  - Allows beam to be directed anywhere from any direction
  - Field size ranges from 5 mm to 60 mm at 80 cm distance
- All walls are typically consider primary barriers
  - Floor also if occupancy below
  - Typical use factor U = 0.05
  - A back wall might be considered secondary if the treatment nodes exclude pointing in that particular direction

CyberKnife®

- All treatments use IMRT, with 15 MU per cGy typical
- 8 Gy at 80 cm SAD for head treatments
- 9.7 Gy at 100 cm SAD for spine/body treatments
- Small use factor and high MU requires both primary and secondary barrier leakage calculations for each wall
- Scatter is negligible compared to primary + leakage
- Ceiling is typically evaluated for leakage only
- Beam can point no higher than 22° above horizontal

ViewRay® MRIdian® System

- The MRIdian® system includes:
- **A rotating gantry assembly** with three Cobalt-60* teletherapy heads and three multileaf collimators.
- **A split-magnet MRI system** for volumetric and multiplanar soft-tissue imaging.
- **A patient couch,** two in-room couch control panels, and a laser positioning system to facilitate initial patient setup.

*6 MV model available now

NEW TECHNIQUES IN RADIATION THERAPY

- **Higher Radiation Workloads used with these new techniques can impact the shielding materials used (high density concrete, lead, borated polyethylene)**
- **Irradiation techniques can impact the geometry to be considered in shielding calculations.**

SHIELDING DESIGN PARAMETERS

- Purpose of radiation shielding is to reduce the effective dose from a linac to a point outside the room to a sufficiently low level as determined by the local or national regulatory bodies for either public (uncontrolled) or occupational (controlled) occupancy.

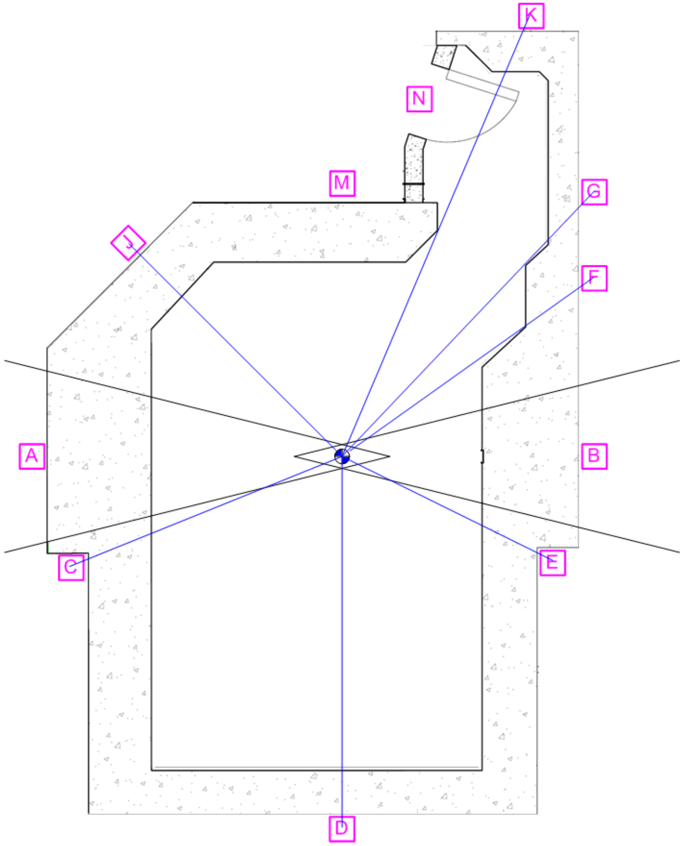
SHIELDING DESIGN PARAMETERS

- The required shielding is calculated based on the weekly workload of the machine at a specific energy, the distance from the target or isocenter from the patient to the point being shielded, the fraction of time that the beam is oriented in that particular direction, and the fraction of time that the space under consideration is occupied.

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE
Advancing the Science, Education & Professional Practice of Medical Physics

LOCATIONS TO BE CALCULATED

- All locations of occupancy
- Locations A & B are primary beam calculations along with the ceiling.
- All other locations are secondary beam calculations for both scatter and leakage photons and neutrons, depending on beam energy.



CHALLENGES IN SHIELDING DESIGN

- Upgrades/Replacement of Prior Linear Accelerator Installations
- If space is available, cheapest additional shielding is concrete blocks which are available in a range of concrete densities.
- If space is limited, use of lead or steel is used. Lead blocks have the advantage of having a TVL almost 1/2 that of steel. However, steel has the advantage of significantly lower photoneutron production.

CHALLENGES IN SHIELDING DESIGN

- Ceilings are a serious challenge: The issue of weight is a significant problem. Steel I-beams must be used to support the weight along with a supporting steel shelf.
- Laminated barriers consisting of both lead and concrete or concrete/lead/borated polyethylene may be used to minimize thickness of required shielding when space is at a minimum.
- Neutron generation is significantly less at 15 MV than at 18 MV.

WORKLOAD (W)

- From NCRP 151: "Time integral of the absorbed-dose rate determined at the depth of the maximum absorbed dose, 1 m from the source"
- 450 Gy/wk typical weekly workload in NCRP 151
  - 30 patients treated per day
  - 3 Gy absorbed dose at isocenter per patient treatment
  - NCRP 151 recommends report based on maximum MV
  - Simplifies report, lower MV has less impact on shielding
- Workload in report must be conservatively high estimate of planned use by facility
  - Workload assumptions must be approved by facility

TYPICAL 2005 NCRP 151 WORKLOAD

Energy (MV)	Patients per day	Workload (Gy/pt)	Workload (Gy/wk)	MU/cGy Ratio	Leakage Workload (Gy/wk) X-Ray	Neutron
15 IMRT	15	3	225	5	1125	1125
15 3D	15	3	225	1	225	225
15 Total	30		450		1350	1350

- **Calculated at highest MV**
- **30 patients per day at highest MV**
- **3 Gy per patient treatment**
- **50% treatments using step-and-shoot IMRT**
- **5 MU per cGy**

TECHNOLOGY TRENDS SINCE 2005

- Flattening Filter Free (FFF) modes
- Higher instantaneous dose rates
- 3D conformal radiation therapy (3D CRT): Potentially higher workload since heathy tissue spared
- Improved IMRT treatment delivery systems
- Lower MU/cGy than traditional step and shoot IMRT

TECHNOLOGY TRENDS SINCE 2005

- Stereotactic Body Radiation Therapy (SBRT)
- Higher treatment fraction increases workload
- Increased Stereotactic RadioSurgery (SRS) with conventional linear accelerators
- Higher treatment fraction increases workload
- Multiple linear accelerator MVs (2 or 3 MVs typical)

WORKLOAD ASSUMPTIONS FOR MULTI-ENERGY LINAC

Energy (MV)	Patients per day	Workload (Gy/pt)	Workload (Gy/wk)	MU/cGy Ratio	Leakage Workload (Gy/wk) X-Ray	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 FOR HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) DUCTS

- Penetration typically located at ceiling level
- Typically immediately above door if maze
- Side wall near corner if direct shielded door
- Shielded with material similar to the door
- Typically ~1/3 as much material required for maze penetration
- Shelf below duct extending ~6 ft from penetration, or wrapping duct with shielding ~6 ft from penetration for direct shielded door

TYPICAL PRIMARY BARRIER

- Primary barrier calculation tends to be relatively accurate if density is well controlled
- Construction contracts should specify 147 lb/ft^3 density - Typical concrete primary barrier thickness
- 8 feet for uncontrolled access full occupancy
- 7 to 7.5 feet for controlled access (adjacent vault) or uncontrolled access partial occupancy (T=0.2) like corridor
- 6.5 to 7 feet for exterior wall with no near high occupancy
- Lead (1” lead = 6” concrete) and steel (2” steel = 6” concrete) can also be used

TYPICAL SECONDARY BARRIER

- Secondary barrier calculation tends to be conservative
- No need for margin on calculated dose rate
- Typical concrete secondary barrier thicknesses:
  - 4 feet for uncontrolled access full occupancy
  - 3.5 feet for controlled access (adjacent vault) or uncontrolled access partial occupancy (T=0.2) like corridor
  - Control area 3.5 to 4 feet depending on proximity to other sources of radiation (adjacent vaults, vault entrances, etc.)
  - 3 feet for exterior back wall with no near high occupancy areas
- Lead (1” lead = 6” concrete) and steel (2” steel = 6” concrete) can also be used

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE
Advancing the Science, Education & Professional Practice of Medical Physics

TYPICAL WORKLOADS AND BARRIER THICKNESSES

Equipment: Varian TrueBeam **Date:** May 27, 2016

Signature: Melissa C. Martin

Physicist:
Melissa C. Martin, M.S., DABR, FACR
Therapy Physics, Inc.
879 W 190th St., Ste. 400, Gardena, CA 90248
310-217-4114, FAX 310-217-4118
e-mail: melissa@therapyphysics.com

------------ Field Size (cm) ------------		
Effective (corners)	Maximum Scatter 18 MV	6 MV
35	40	40

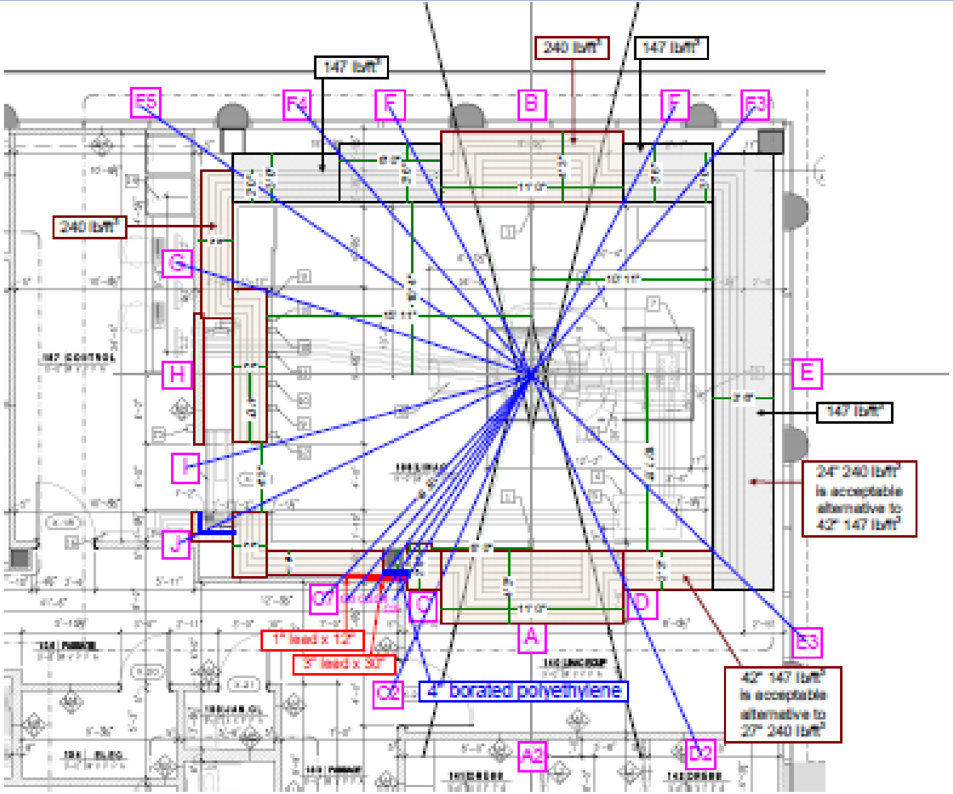
Energy (MV)	Patients per day	Workload (Gy/pt)	Workload (Gy/wk)	MU/cGy Ratio	Leakage Workload (Gy/wk) X-Ray	Neutron	
18 RapidArc	5	3	75	3	225	225	
18 3D	15	3	225	1	225	225	
18	20		300		450	450	Total
6 RapidArc	15	3	225	3	675	NA	
6 3D	5	3	75	1	75	NA	
6	20		300		750	NA	Total

Primary Barrier Summary

	Inner Barrier Layer		*Outer Barrier Layer*		*P/T*	*Shielded Dose*
Protected Location	*Thickness*	*Material*	*Thickness*	*Material*	*(mSv/week)*	*(mSv/week)*
A - Linac equipment room			51 in	Concrete-240	0.400	0.031
A2 - Changing room			51 in	Concrete-240	0.100	0.017
A3 - Dosimetry			51 in	Concrete-240	0.020	0.005
B - North exterior			51 in	Concrete-240	0.400	0.030
B2 - adj building north			51 in	Concrete-240	0.020	0.006

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE
Advancing the Science, Education & Professional Practice of Medical Physics

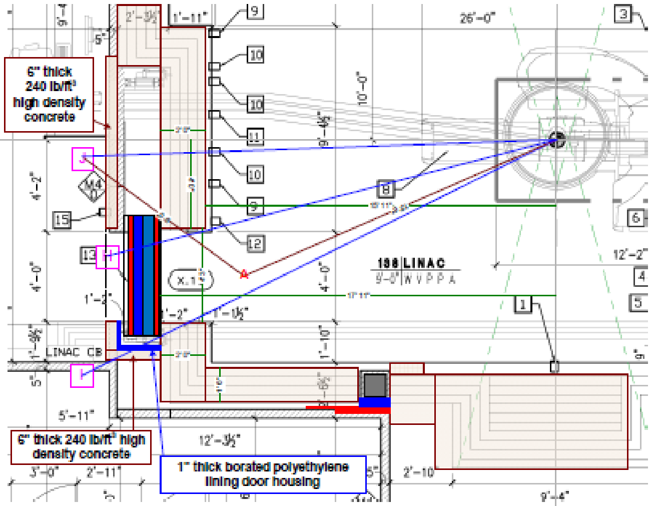
TRUEBEAM VAULT IN MEDICAL OFFICE BUILDING



RadNet Tarzana
Linear Accelerator Vault
18133 Ventura Boulevard,
Tarzana, Los Angeles, CA 91356

A1.1 (05-27-2015)

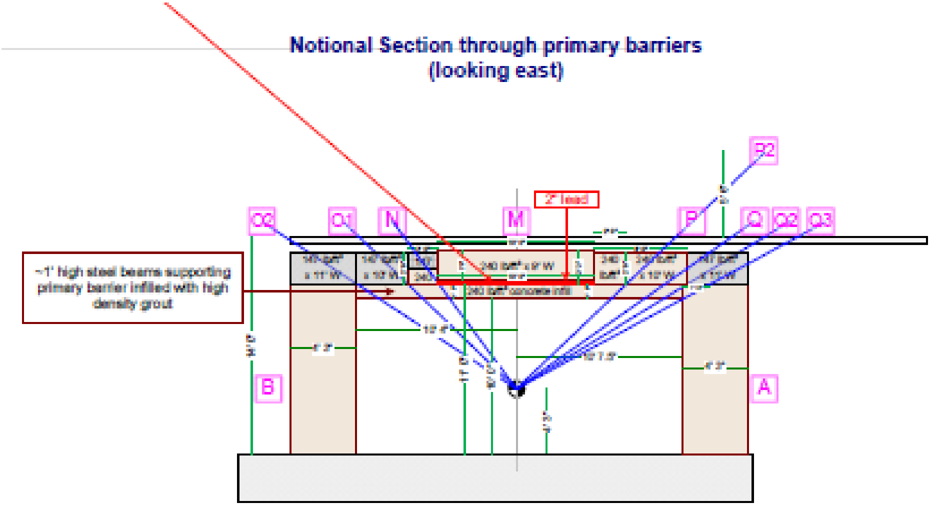
Entrance Shielding Details

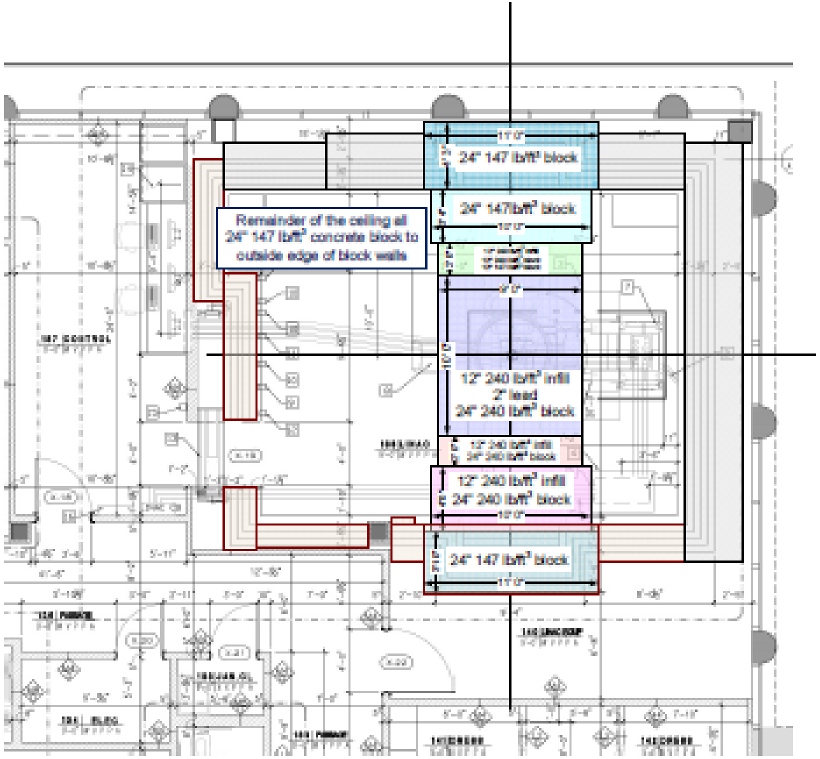


Door to contain 3" lead inner layer (toward vault interior) followed by 6" normal polyethylene, 5" borated polyethylene and an outer layer of 3" lead, with minimum 0.25" steel covers

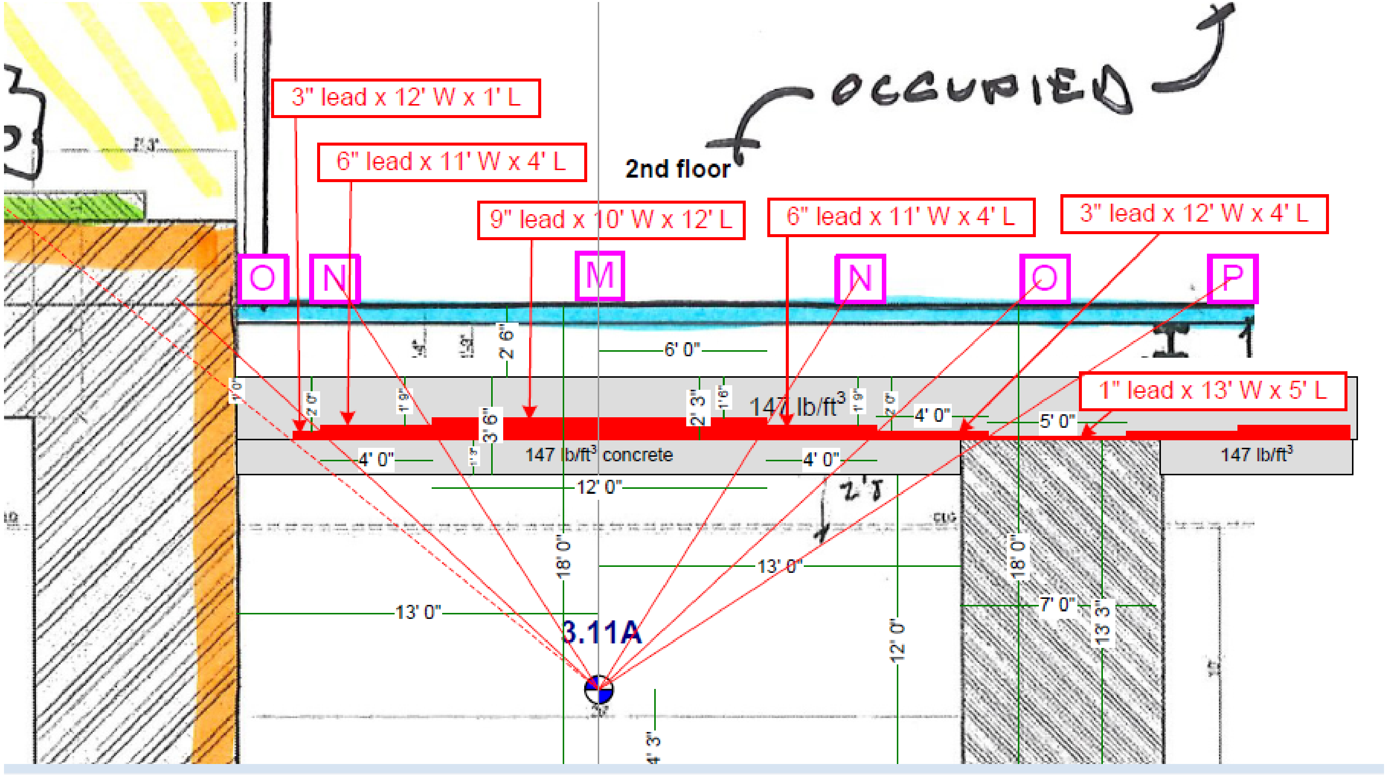
Note: door must have 7.5" overlap of lead / concrete in wall when closed.
Calculations assume a nominal gap of 0.5" between the door and outside of the wall.
The maximum gap must not exceed 0.75".

CEILING SHIELDING





CEILING EXAMPLE SHIELDING WITH LEAD BRICK FOR LINAC

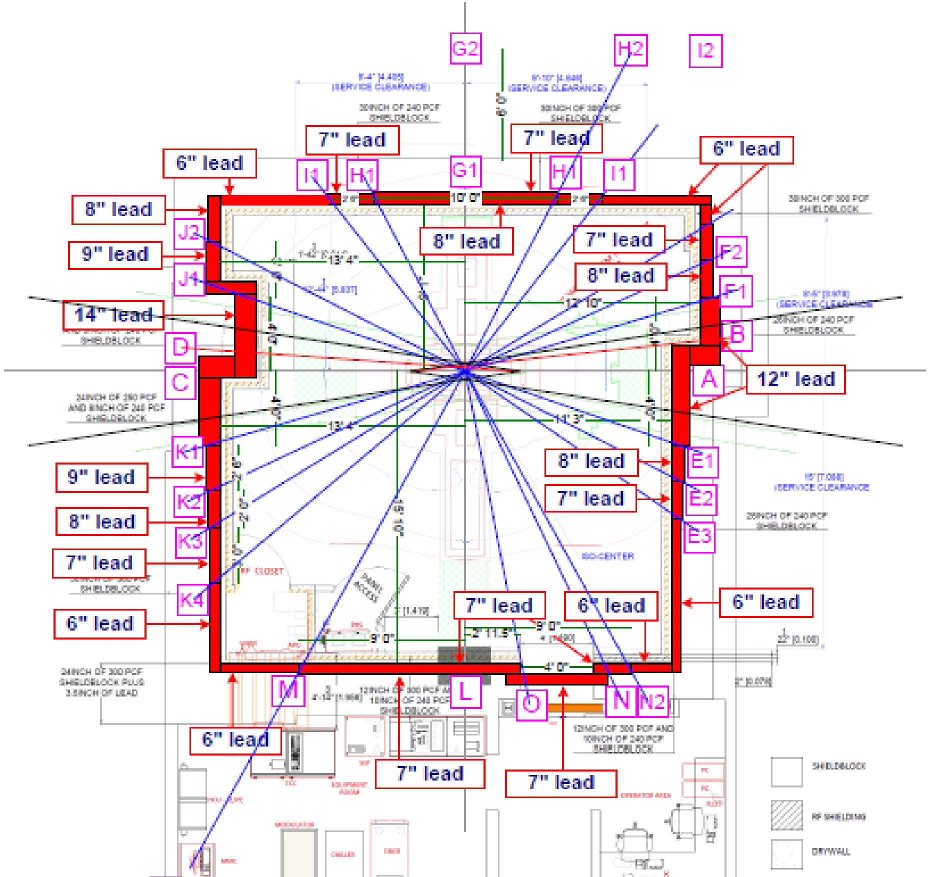


6 MV VIEWRAY PLAN

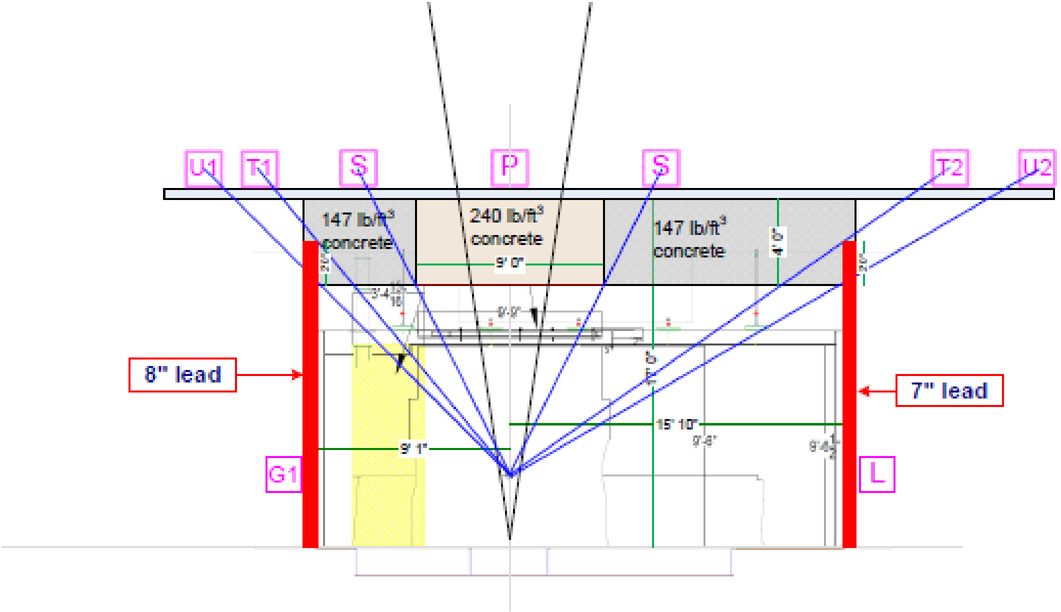
Note: door must have 7.5” overlap of lead concrete in wall when closed. Calculations assume a nominal gap of 0.5” between the door and outside of the wall.

The maximum gap must not exceed 0.75”.

Door to contain 7" lead with minimum 0.25” steel covers

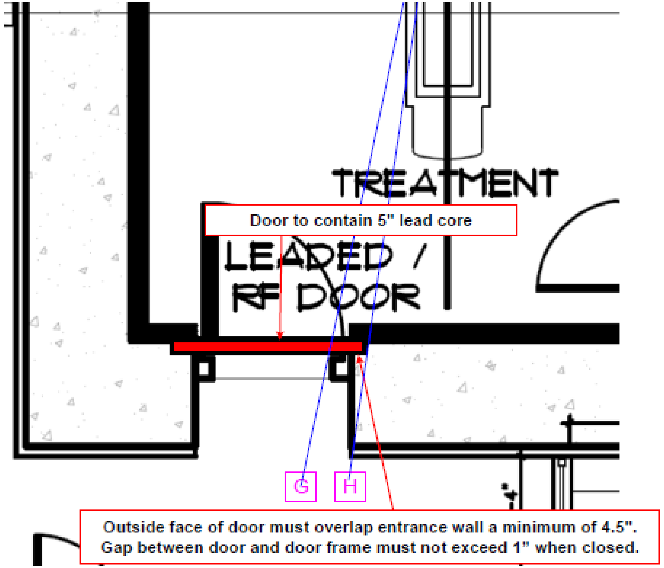


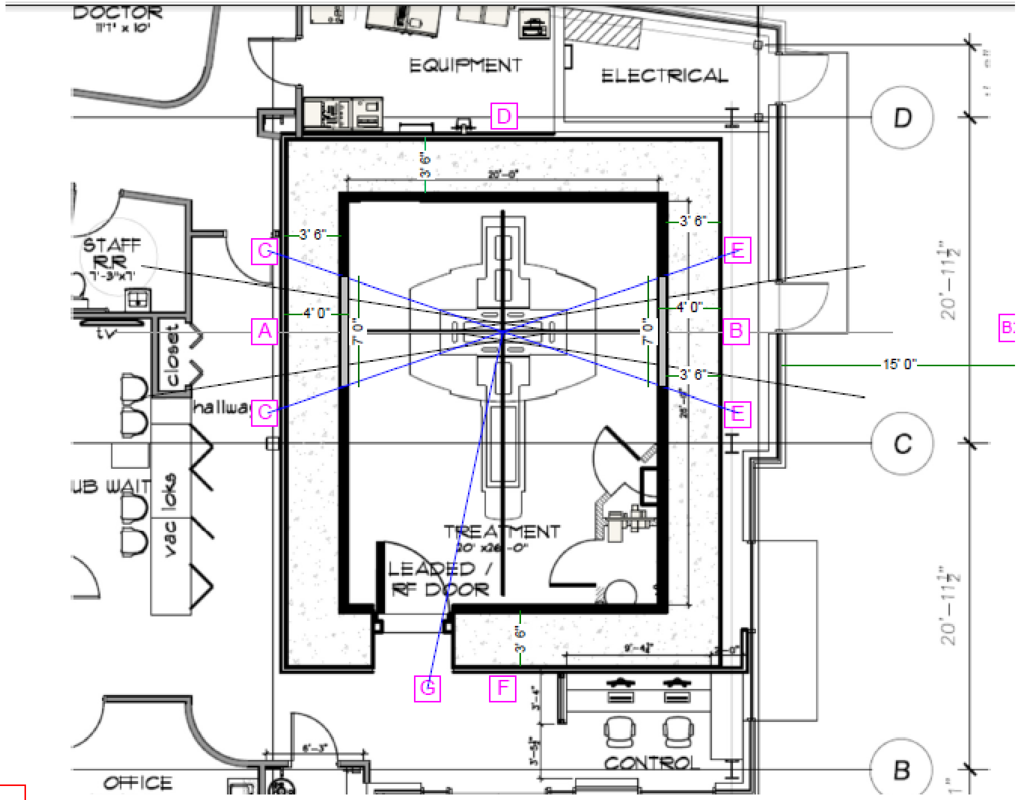
VIEWRAY - 6 MV ELEVATION VIEW



AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE
Advancing the Science, Education & Professional Practice of Medical Physics

COBALT VIEWRAY





TOMOTHERAPY INSTALLATION IN FORMER 6 MV VAULT

Signature: Draft Shielding Design

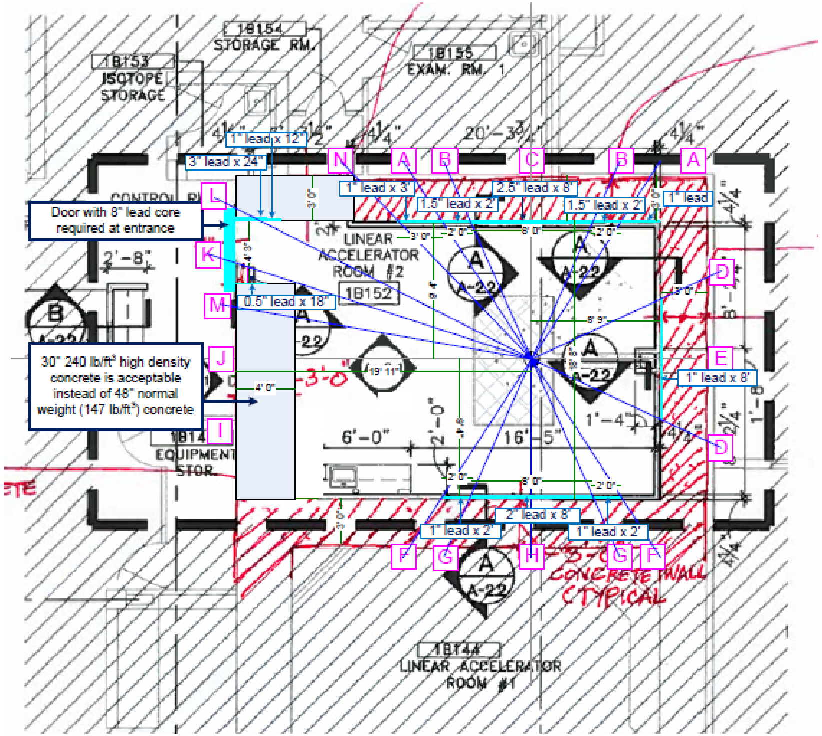
Melissa C. Martin, M.S., DABR, FACR
Therapy Physics, Inc.
879 W 190th St., Ste. 419, Gardena, CA 90248
310-217-4114, FAX 310-217-4118
e-mail: melissa@therapyphysics.com

Field Size (cm) Effective (Corners)	Maximum (Scatter)	Linac Vendor
35	40.0	Tomotherapy

Energy (MV)	Patients per day	Workload Gy/pt	Workload (Gy/wk)	IMRT Ratio (MU/cGy)	Percent IMRT	Leakage WL (Gy/wk) X-Ray	Neutron
6	35	3	525	16	100%	8400	NA

Secondary Barrier Summary

Protected Location	*Inner Barrier Layer Thickness*	*Material*	*Outer Barrier Layer Thickness*	*Material*	*P/T (mSv/week)*	*Shielded Dose (mSv/week)*
A - Exam room	1.0 in	Lead	36 in	Concrete	0.040	0.022
B - Exam room	2.0 in	Lead	36 in	Concrete	0.040	0.016
C - Exam room	3.0 in	Lead	36 in	Concrete	0.040	0.016
D - Exterior			36 in	Concrete	0.400	0.225
E - Exterior	1.0 in	Lead	36 in	Concrete	0.400	0.175
F- Therapy Vault			36 in	Concrete	0.200	0.093
G - Therapy Vault	1.0 in	Lead	36 in	Concrete	0.200	0.060
H - Therapy Vault	2.0 in	Lead	36 in	Concrete	0.200	0.048
I - Equipment room			48 in	Concrete	0.100	0.015
J - Control room			48 in	Concrete	0.100	0.021
J - Control room (HD conc)			30 in	Concrete-240	0.100	0.016
N - Exam room			36 in	Concrete	0.040	0.016



CYBERKNIFE INSTALLATION

Signature: ______________________

Physicist:
Melissa C. Martin, M.S., DABR, FACR
Therapy Physics, Inc.
879 W 190th St., Ste. 419, Gardena, CA 90248
310-217-4114, FAX 310-217-4118
e-mail: melissa@therapyphysics.com

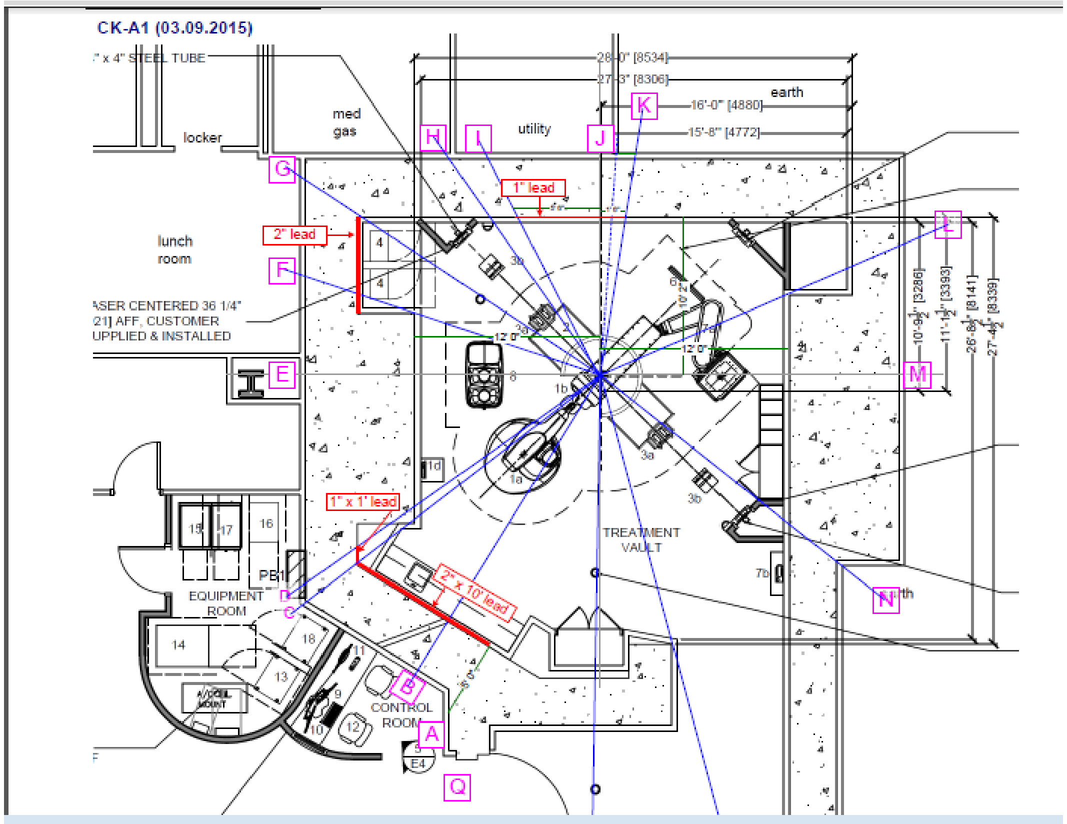
Max Field Size (cm)	Linac Vendor
7.5	Accuray

Energy (MV)	Patients per day	Workload Gy/pt	Workload (Gy/wk)	IMRT Ratio (MU/cGy)	Percent IMRT	Leakage WL (Gy/wk) X-Ray	Leakage WL (Gy/wk) Neutron
6	8	12.8	512	12	100%	6144	NA

The above workload is normalized to 1 m SAD and corresponds to 20.0 Gy/pt at 80 cm SAD.

Primary + Secondary Barrier Summary (Walls)

Protected Location	*Inner Barrier Layer Thickness*	*Inner Barrier Layer Material*	*Outer Barrier Layer Thickness*	*Outer Barrier Layer Material*	*P/T (mSv/week)*	*Shielded Dose (mSv/week)*
A - Control area			60 in	Concrete	0.100	0.010
B - Control area	2.0 in	Lead	44 in	Concrete	0.100	0.024
C - Equipment room	1.0 in	Lead	44 in	Concrete	0.100	0.030
D - Equipment room	12 in	Concrete	40 in	Concrete	0.100	0.008
E - Mold room			84 in	Concrete	0.100	0.000
F - Lunch room	2.0 in	Lead	40 in	Concrete	0.100	0.038
G - Lunch room			42 in	Concrete	0.100	0.075
H - Med Gas			44 in	Concrete	0.400	0.075
I - Utility			44 in	Concrete	0.400	0.139
J- Utility	1.0 in	Lead	44 in	Concrete	0.400	0.145
K - Exterior (below ground)	44 in	Concrete	3 ft	Earth	0.400	0.005
L - Exterior south	36 in	Concrete	3 ft	Earth	0.400	0.005
M - Exterior south	84 in	Concrete	0 ft	Earth	0.400	0.000
N - Exterior south	36 in	Concrete	3 ft	Earth	0.400	0.002



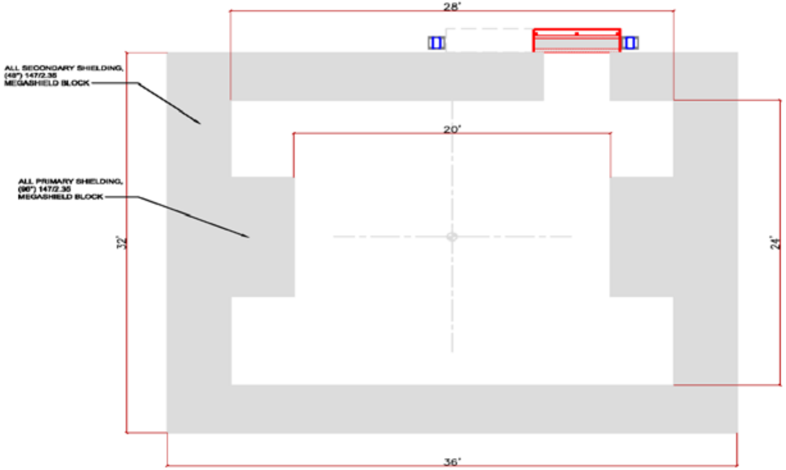
SUMMARY AND CONCLUSIONS

Gone are the days of easy simple shielding designs!

Must get accurate data for workloads - this is major determinant of shielding requirements

Work with the architect as early as possible to know the hard limits of size of facility available to use for shielding.

MEGASHIELD



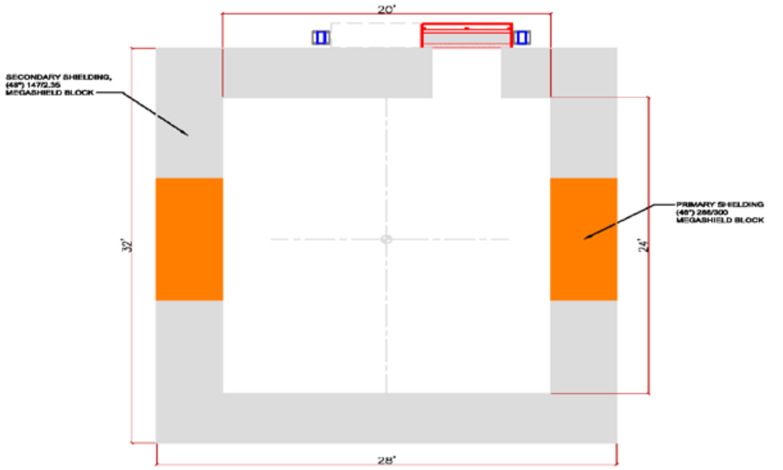
MEGASHIELD BLOCK VAULT — 147# CONCRETE

- Typical Standard Weight direct entry Megashield Modular Vault

Physics assumptions:

- Dual energy 6 & 18 Mev accelerator. (each site will requires physics design by a licensed physicist) We are making the following assumptions in order to provide a ROM cost estimate
  - 48” thick secondary walls 147# Concrete
  - 96” primary walls 147# concrete
- Interior Dimensions 20’-0” x 24’-0”
- Exterior Dimensions: 32’-0”x 36’-0”
- Base ROM Cost for this Vault
    - $375,000 to $400,000 dollars
  - Mazeless Slide Door System
    - $95,000 to $105,000 dollars
  - HVAC Shielding Rack

HYBRID MEGASHIELD



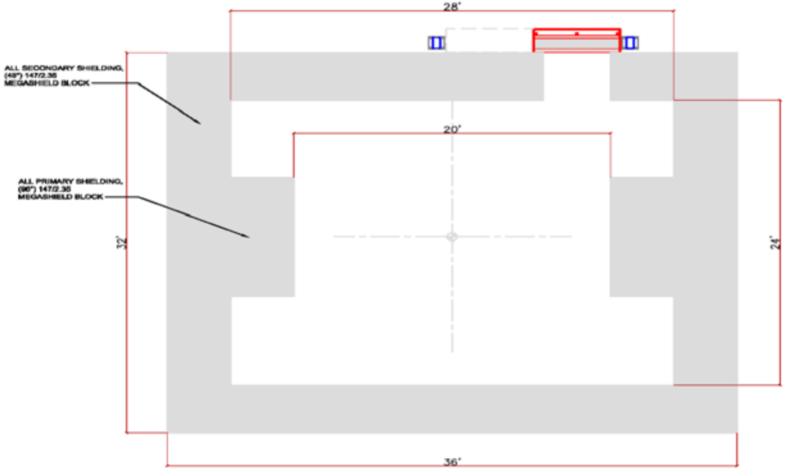
MEGASHIELD BLOCK VAULT — 147 SECONDARY — 288/300 PRIMARY

- Hybrid High Density direct entry Megashield Modular Vault

Physics assumptions:

- Dual energy 6 & 18Mev accelerator. (each site will requires physics design by a licensed physicist) We are making the following assumptions in order to provide a ROM cost estimate
  - 48” thick secondary walls 147# Concrete
  - 60” primary walls 240/250# concrete
- Interior Dimensions: 20’-0” x 24’-0”
- Exterior Dimensions: 28’-0”x 32’-0”
- Base ROM Cost for this Vault
    - $525,000 to $575,000 dollars
  - Mazeless Slide Door System
    - $95,000 to $105,000 dollars
  - HVAC Shielding Rack

MEGASHIELD



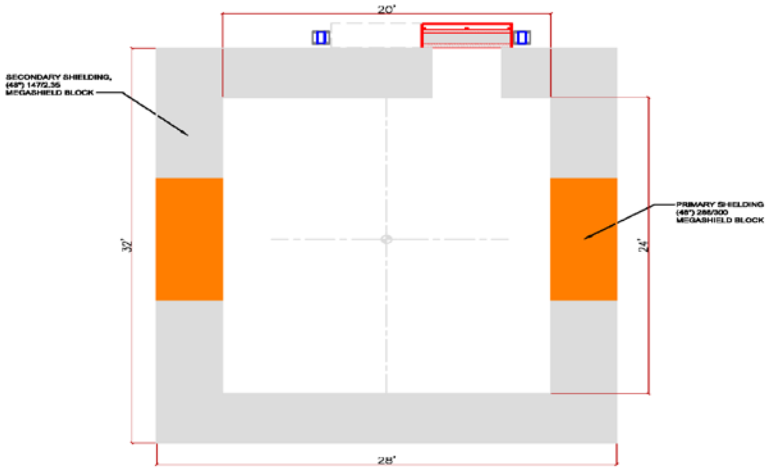
MEGASHIELD BLOCK VAULT – 147# CONCRETE

- Typical Standard Weight direct entry Megashield Modular Vault

Physics assumptions:

- Dual energy 6 & 18 Mev accelerator. (each site will requires physics design by a licensed physicist) We are making the following assumptions in order to provide a ROM cost estimate
  - 48” thick secondary walls 147# Concrete
  - 96” primary walls 147# concrete
- Interior Dimensions 20’-0” x 24’-0”
- Exterior Dimensions: 32’-0”x 36’-0”
- Base ROM Cost for this Vault
    - $375,000 to $400,000 dollars
  - Mazeless Slide Door System
    - $95,000 to $105,000 dollars
  - HVAC Shielding Pack

HYBRID MEGASHIELD



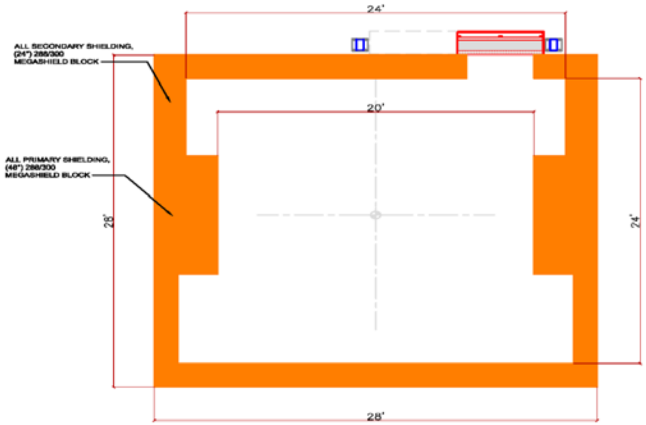
MEGASHIELD BLOCK VAULT – 147 SECONDARY – 288/300 PRIMARY

- Hybrid High Density direct entry Megashield Modular Vault

Physics assumptions:

- Dual energy 6 & 18Mev accelerator. (each site will requires physics design by a licensed physicist) We are making the following assumptions in order to provide a ROM cost estimate
  - 48” thick secondary walls 147# Concrete
  - 60” primary walls 240/250# concrete
- Interior Dimensions: 20’-0” x 24’-0”
- Exterior Dimensions: 28’-0”x 32’-0”
- Base ROM Cost for this Vault
    - $525,000 to $575,000 dollars
  - Mazeless Slide Door System
    - $95,000 to $105,000 dollars
  - HVAC Shielding Rack

HYBRID MEGASHIELD



MEGASHIELD BLOCK VAULT – 288/300 CONCRETE

- Hybrid High Density direct entry Megashield Modular Vault

Physics assumptions:

- Dual energy 6 & 18Mev accelerator. (each site will requires physics design by a licensed physicist) We are making the following assumptions in order to provide a ROM cost estimate.
  - 24” thick secondary walls 288/300# Concrete
  - 48” primary walls 288/300# concrete
- Interior Dimensions: 20’-0” x 24’-0”
- Exterior Dimensions: 28’-0”x 28’-0”
- Base ROM Cost for this Vault
    - $750,000 to $775,000 dollars
  - Mazeless Slide Door System
    - $95,000 to $105,000 dollars
  - HVAC Shielding Rack

THANK YOU!

CONTACT INFORMATION

Melissa C. Martin, M.S., FACR, FAAPM
Certified Medical Physicist
Therapy Physics, Inc.
879 W 190th Street, Suite 400, Gardena, CA 90248
Office Phone: 310-217-4114
Office Fax: 310-217-4118
Cell Phone: 310-612-8127
E-mail: melissa@therapyphysics.com