Authorization and Inspection of Linear Accelerators Used in Radiotherapy
Day 3



IAEA
International Atomic Energy Agency

Agenda

- Day 3
  - Training Requirements for Facility Staff
  - Facility Construction Criteria
  - Shielding Calculation Methods

Linear Accelerator Staffing

Linear Accelerator Staffing

- Learning Objectives
  - *After this section, the students should understand the personnel involved in delivering a dose to a patient from a linear accelerator safely and the level of training required for these persons.*
- This section should take 60 minutes

Linear Accelerator Staffing

- Complex procedure with many critical roles
- Training and collaboration is essential to:
  - Deliver a safe treatment
  - Develop a comprehensive quality assurance program
  - Keep workers safe

Linear Accelerator Staffing

- Common Staffing of a Radiation Oncology Program:
  - Radiation Therapist
  - Dosimetrist
  - Medical Physicist
  - Radiation Oncologist
  - Nurse
  - Radiation Safety Officer
  - Clinical Engineer

Linear Accelerator Staffing

- Radiation Therapist
- Responsible for treatment delivery
  - Daily output check in accordance with Medical Physicist procedures
  - Patient and parameter verification, correct plan, correct treatment site
  - Patient Positioning in accordance with chart instructions
  - Inform the physician and seek advice if the female patient is pregnant or likely to be pregnant;
  - Inform the physician in case you are concerned about an unusual reaction of patient;

Linear Accelerator Staffing

- Radiation Therapist
- Training Requirements
  - Should be trained in the procedures developed by the Medical Physicist
  - Overseen by the Medical Physicist
    - Review of daily output checks should be done within 15 days
  - Overseen by the Radiation Oncologist
    - Patient positioning

Linear Accelerator Staffing

- Dosimetrist
  - Performs patient dose calculations, verifies calculation accuracy, treatment documentation.
  - Provides technical and physics support to the Medical Physicist.
  - Participates in the education of residents and students.

Linear Accelerator Staffing

- Dosimetrist
  - Training Requirements
    - Overseen by Medical Physicist and Radiation Oncologists
    - Procedures should be developed
    - Treatment plans reviewed by Medical Physicists
    - Prescriptions and Treatment Plans must only be signed off by Radiation Oncologist

Linear Accelerator Staffing

- Medical Physicist
- Responsible for Accelerator Maintenance and Output
  - Measurement and Calibration of Linear Accelerator
  - Maintenance of Measurement Equipment
  - Treatment Planning System
  - Quality Assurance Procedures

Linear Accelerator Staffing

- Medical Physicist
- Explicitly identified on the license document
- Many may be identified on any license
- Typical training requirements
  - Master's degree in physics, medical physics, other physical science, engineering, or applied mathematics from an accredited college or university
  - 2 years on the job training
  - Device specific training

Linear Accelerator Staffing

- Radiation Oncologist
- Responsible for Patient Care
  - Written Directive
  - Treatment Plan
  - Weekly patient visits and follow-up
  - Patient Chart Documentation and Reviews

Linear Accelerator Staffing

- Radiation Oncologist should ensure:
  - That the exposure of normal tissue is kept as low as reasonably achievable while required dose is delivered to the planning target volume;
  - Establish optimized protocols for therapeutic procedures, in consultation with the medical physicist;
  - Ensure radiotherapeutic procedures of women who are pregnant or likely to be pregnant be avoided unless there are strong clinical indications;
  - Evaluate any radiation accident or incident from a medical point of view.

Linear Accelerator Staffing

- Radiation Oncologist
- Explicitly identified on the license document
- Many can be identified on any license
- Typical training requirements
  - Medical Doctorate
  - 3 years Radiation Oncology Residency training
  - Device specific training
- Explicitly listed on the license

Linear Accelerator Staffing

- Nursing
- Assists with Patient Care
  - Medical History
  - Vital Signs
  - Patient Education

Linear Accelerator Staffing

- Radiation Safety Officer (RSO)
- Responsible for Implementation of Radiation Safety Program
  - Radiation Safety Committee Maintenance
  - Annual Training Requirements
  - Occupational Monitoring
    - Declared Pregnancies
  - Compliance with Regulations
  - Correspondence with Regulators

Linear Accelerator Staffing

- Radiation Safety Officer (RSO)
- Explicitly identified on the license document
- Only one primary and one alternate are identified on any license
- Typical training requirements
  - Master's degree in physics, medical physics, other physical science, engineering, or applied mathematics from an accredited college or university
  - 1 year on the job training
  - 200 hours classroom training
  - Device specific training

Linear Accelerator Staffing

- Ongoing Training Requirements
- Initial and Annual training for all users
  - Emergency Procedures
  - Radiation Safety
  - Regulatory Requirements
  - Remedial
  - Security
- Job Specific training
  - Radiation Therapist
  - Dosimetrist

Quiz-Questions

1. Which roles are listed explicitly on the license?
2. Which role is responsible for developing and implementing the QA program?
3. Which role serves as a liaison to the regulatory agency?

Quiz-Answers

1. Which roles are listed explicitly on the license?

RSO, Radiation Oncologist, Medical Physicist

2. Which role is responsible for developing and implementing the QA program?

Medical Physicist

3. Which role serves as a liaison to the regulatory agency?

RSO

Exercise 4: User Qualification Review

This exercise should take 60 minutes

Facility Construction Criteria

Facility Construction Criteria

- Learning Objectives
  - *After this section, the students should understand the key considerations made in facility construction and the process for approval of a facility design*.

- This section should take 60 minutes

Facility Construction Criteria

- Radiotherapy departments are usually located on the periphery of the hospital or clinic complex to avoid radiation protection problems arising from therapy rooms being adjacent to high occupancy areas.

- For rooms on or above ground level, the outside walls always require shielding; and additional structural support may be required for heavy equipment and for the additional weight of the shielding barriers.

Facility Construction Criteria

- The amount of shielding required in each of the barriers of the treatment barriers of the vault will depend to some extent on the use of the surrounding areas. Areas with high occupancy levels will require greater shielding.

- Wherever possible the treatment vault should be surrounded with rooms that have low or controlled occupancy. For example locks or signs prohibiting unauthorized entry could control access to the roof space above the vault.

Facility Construction Criteria

- In order to reduce the radiation dose near the entrance, a restricted access passageway leading to the room may be incorporated in the design. This passageway is termed the maze.

- A maze ensures that photon radiation can only exit the room after scattering has attenuated it and reduces the need for a heavy shielding door.

Facility Construction Criteria

- It is necessary to include in the room design an open access conduit for dosimetry equipment cables. This dosimetry duct should always be through a secondary barrier so that the primary beam can never strike it.

- Ideally it should run at an angle through the barrier to the treatment control area.

Facility Construction Criteria

- All doors, gates, photoelectric beams and motion detectors must be interlocked to the treatment unit to prevent an exposure if a door is open. The interlock must also ensure that when the door is opened the irradiation will be terminated.

- The radiation output of the device should not be resumed automatically after the door is closed again.

Facility Construction Criteria

- The operator should be able to visually monitor the patient during treatment with closed circuit TV. Two cameras are recommended situated 15 degrees off and above the gantry rotation axis for optimum observation of the patient on the treatment couch.

- A two-way audio communication between the treatment control area and the room is required. A patient activated alarm may be required for patients unable to give an audible call.

Facility Construction Criteria

- Paragraph I.23 of the International Basic Safety Standards (BSS) requires registrants and licensees to “display a warning symbol, such as that recommended by the International Organization for Standardization (ISO)…at access points and other appropriate locations within controlled areas.”

- An illuminated warning sign be displayed at the entrance to the maze or treatment vault as well as several inside the treatment vault. It should be possible to see a warning sign from any position within the treatment vault

Facility Construction Criteria

- These signs should be mounted at eye level (1650 mm above finished floor level) and interlocked with the treatment unit control.



Facility Construction Criteria

- New construction
  - Plans submitted prior to construction
    - Verifies calculations
    - Calculation basis National Counsel Radiation Protection (NCRP) report number 151
  - Shielding Evaluation verified prior to first patient treatment

Facility Construction Criteria

- Reusing existing construction
  - Shielding Evaluation submitted prior to new use
  - Shielding verified prior to patient treatment

Facility Construction Criteria

- For new radiation treatment facilities, concrete will usually be the material of choice since it is the least expensive. However, if space is at a premium it may be necessary to use a higher density building material

- Concrete density will vary according to the aggregate used. Most published data assume a density for concrete of 2350 $kg \cdot m^{-3}$

- For therapy installations operating above 10 MV, shielding against neutrons must be considered

Facility Construction Criteria

- Concrete contains a relatively high hydrogen content and is therefore efficient at shielding against fast neutrons

- The tenth value layer (TVL) for the primary X ray beam is approximately double that for the photoneutrons produced by medical linear accelerators, so any shield designed as a primary barrier against X rays will be more than adequate against photoneutrons

Facility Construction Criteria

- The TVL of 0.34 MeV photoneutrons in concrete is about 210 mm.
- The TVL in concrete for high energy X rays (10–25 MeV) is about 400–500 mm.
- If the shielding is adequate for photons it will also be adequate for neutrons

Shielding Construction Guidance

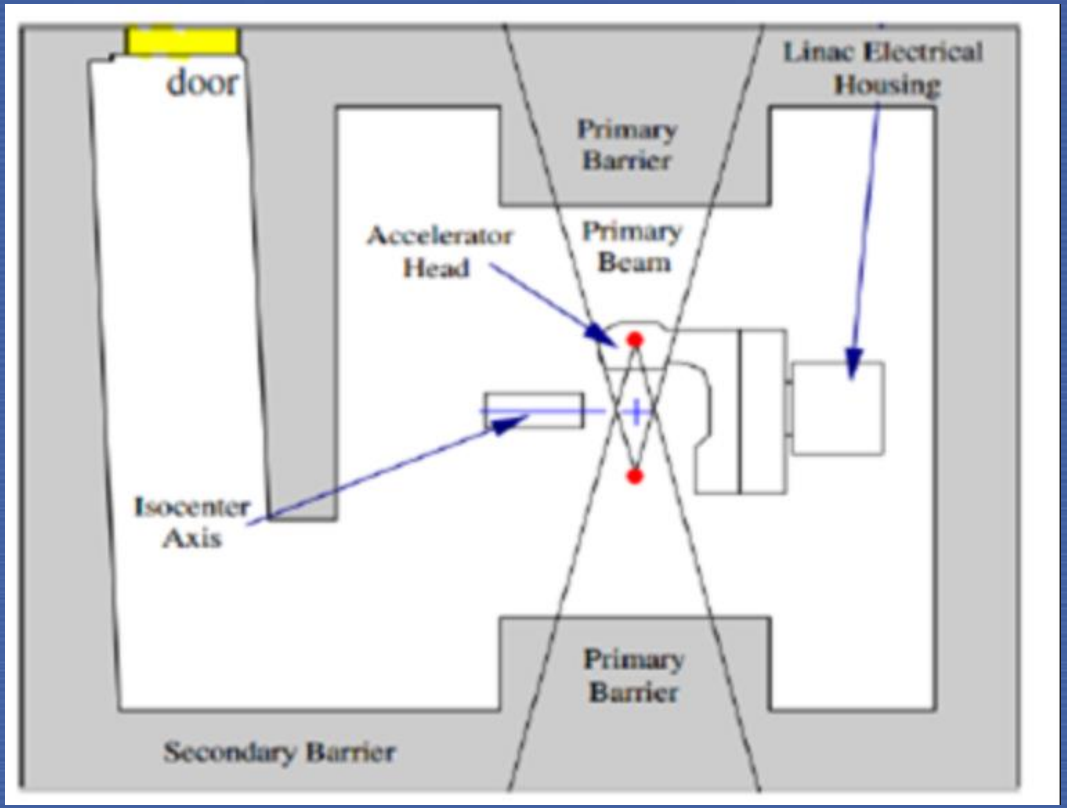
- National Council Radiation Protection Report No. 151 (NCRP 151), “Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities”

- IAEA Report No. 47, “Radiation Protection in the Design of Radiotherapy Facilities”

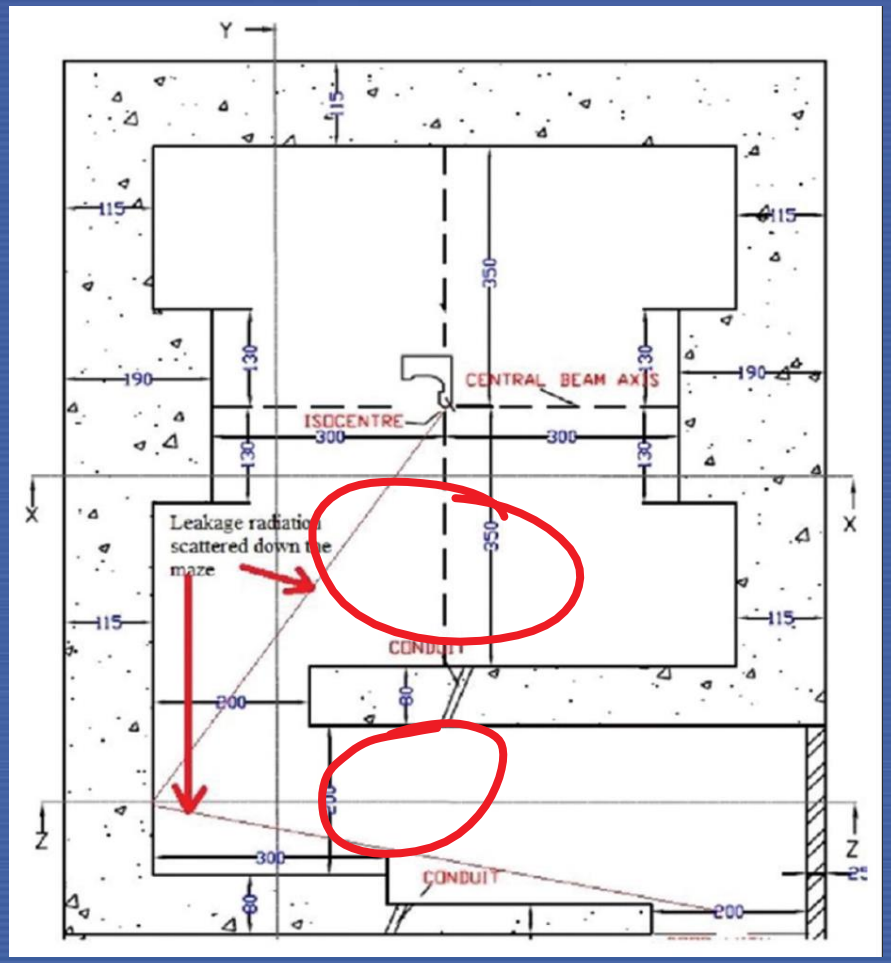
Facility Shielding Verification

- Calculations verified prior to construction or machine turn-on
- Confirmatory Survey
  - Licensee
  - Regulatory Authority
  - On-going Monitoring

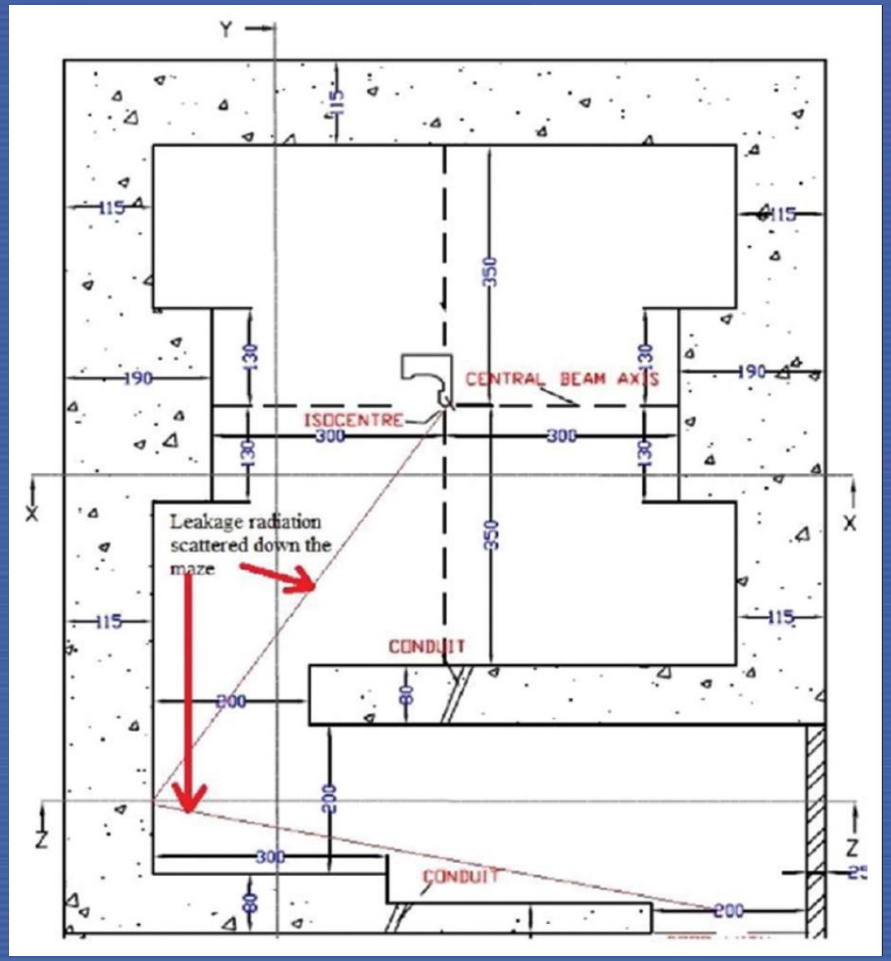
Facility Shielding Diagram



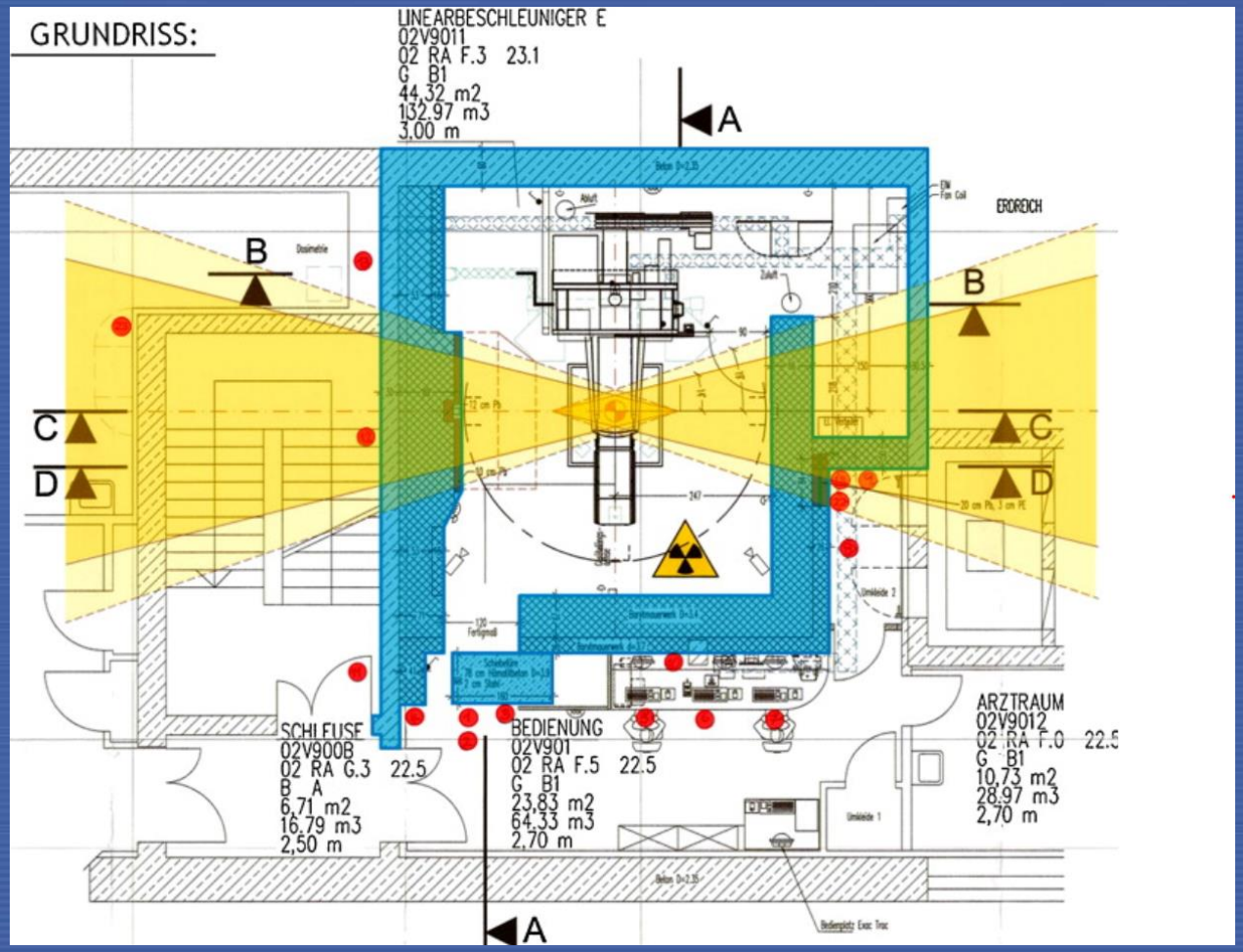
Facility Shielding Diagram



Facility Shielding Diagram



Facility Shielding Diagram



Quiz-Questions

1. On what level are LINAC vaults typically constructed, and why?
2. Where should ductwork/conduits pass through and what shape should they take? Why?
3. When replacing a LINAC the previous shielding may be sufficient if this is true?
4. For 18MV LINACs, how much additional concrete is required to shield photo-neutrons?

Quiz-Answers

1. On what level are LINAC vaults typically constructed, and why?

   Ground level or basement

2. Where should ductwork/conduits pass through and what shape should they take? Why?

   Secondary barrier at an angle

3. When replacing a LINAC the previous shielding may be sufficient if this is true?

   Equal or lesser energy

4. For 18MV LINACs, how much additional concrete is required to shield photo-neutrons?

   None

Lunch

Shielding Calculation Methods

Shielding Calculations

- Learning Objectives
  - After *this section, the students should know primary vs secondary barriers, the different shielding materials and their properties, and how shielding calculations are performed.*
- This section should take about 90 minutes

Shielding Calculation Methods

- Shielding calculations estimate radiation exposure to staff and members of the public due to the use of the LINAC.
  - Includes details such as building materials and thicknesses
  - A wall may have more than one material
- Shielding calculations are theoretical and submitted for review prior to construction.
- After construction and LINAC installation the sufficiency of shielding is verified through radiation surveys.

Shielding Calculation Methods

- The thickness of radiation barriers will depend on the radiation dose limits for public and workers in occupied areas around the linear accelerator.

- To determine the barrier thickness required to shield radiation to the dose limit, it is necessary to estimate the workload of the linear accelerator and to know the radiation dose rate at which the treatment unit will operate.

Shielding Calculation Methods

- Requirement 12, item 3.26. The government or the regulatory body shall establish and the regulatory body shall enforce compliance with the dose limits specified in Schedule III for occupational exposures and public exposures in planned exposure situations.

Shielding Calculation Methods

- Schedule III.3. For public exposure, the dose limits are:

  (a) An effective dose of 1 mSv in a year;

  (b) In special circumstances, a higher value of effective dose in a single year could apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year;

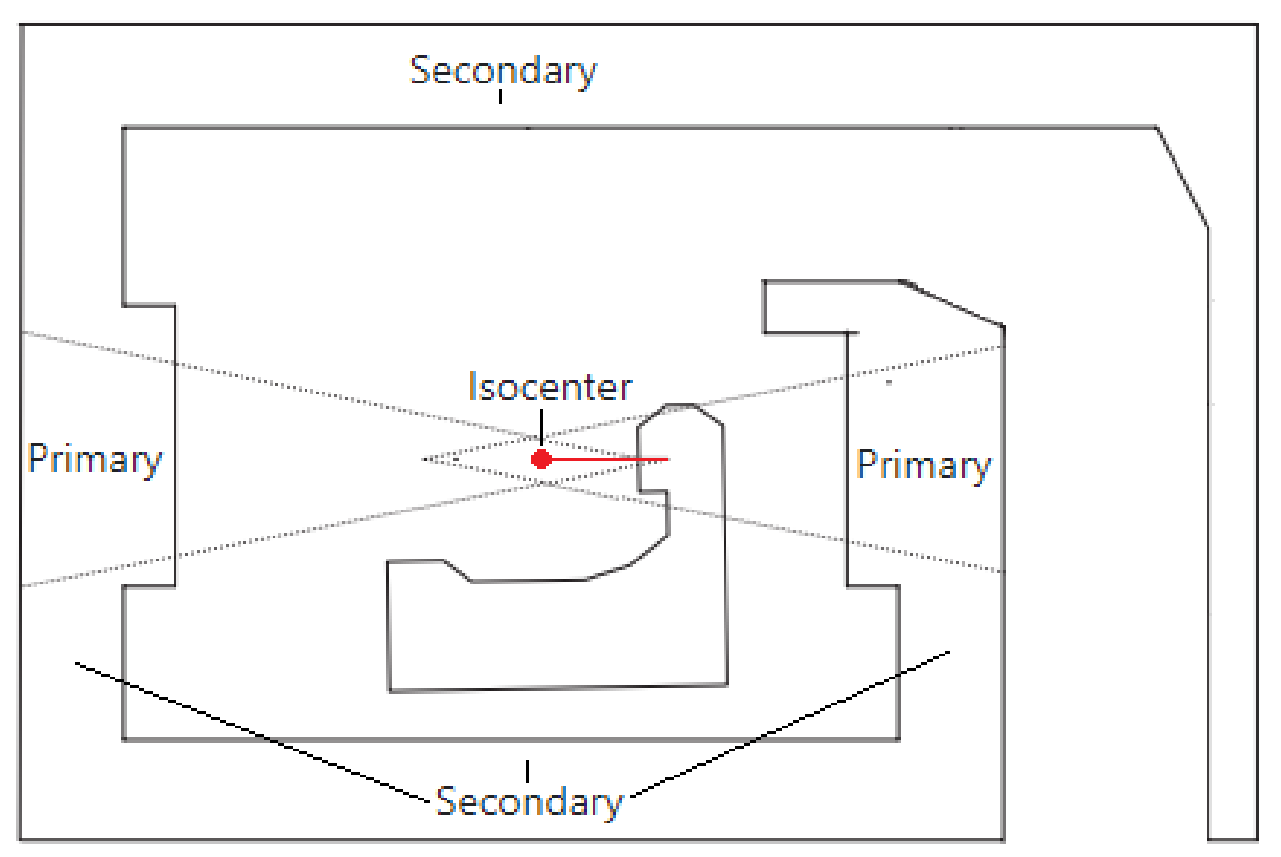
  (c) An equivalent dose to the lens of the eye of 15 mSv in a year;

  (d) An equivalent dose to the skin of 50 mSv in a year

Shielding Calculation Methods

- The required barrier thicknesses are calculated using a tool called the instantaneous dose rates (IDR) which are based on public dose limits.
- The IDR values should be calculated at each point of interest (i.e. outside all primary and secondary barriers and the entrance),
- The IDR values must be compared with direct measurement from the radiation survey conducted following the installation of the treatment unit in the shielding evaluation submitted to the regulator.

Primary vs Secondary Barriers



PRIMARY BARRIERS

Weekly dose rate - The required attenuation of the barrier B may be determined according to a desired dose constraint (design limit, P) that is derived from an occupational or public dose limit.

$$B = \frac{P(d + SAD)^2}{WUT}$$

PRIMARY BARRIERS

$$B = \frac{P(d + SAD)^2}{WUT}$$

P is the allowed dose per week ($Sv \cdot week^{-2}$) outside the barrier;

d is the distance from the isocenter to the outside of the barrier, in m;

SAD is the source–axis (isocenter) distance, in m;

W is the workload, in $Gy \cdot week^{-1}$ at 1 m;

U is the use factor or fraction of time that the beam is likely to be incident on the barrier;

T is the occupancy factor or the fraction of time that the area outside the barrier is likely to be occupied

Occupancy Factors

TABLE 13.2

Location	Occupancy Factor (T)
Full occupancy areas (areas occupied full-time by an individual), *e.g.*, administrative or clerical offices; treatment planning areas, treatment control rooms, nurse stations, receptionist areas, attended waiting rooms, occupied space in nearby building	1
Adjacent treatment room, patient examination room adjacent to shielded vault	1/2
Corridors, employee lounges, staff rest rooms	1/5
Treatment vault doors[b]	1/8
Public toilets, unattended vending rooms, storage areas, outdoor areas with seating, unattended waiting rooms, patient holding areas, attics, janitors' closets	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), stairways, unattended elevators	1/40

TABLE 3. DIFFERENT SUGGESTED OCCUPANCY FACTORS (T)
(*whenever possible, the local situation should be assessed before determining the occupancy factor to be used*)

Type of area	NCRP 49 [2]	BIR/IPEM 2000 [12]
Offices, reception areas, laboratories, shops, children's play areas, nurse's stations, staff rooms Control room	1	1
Wards, patient rooms	1	0.2
Patient examination and treatment rooms	—	0.5
Corridors	1/4	0.2
Toilets, bathrooms, outside areas with seating	1/16	0.1
Stairways, unattended waiting rooms, store rooms (not film)	1/16	0.05

PRIMARY BARRIERS

- The thickness of concrete required can be determined from attenuation graphs or using TVLs. The number of TVLs required to produce this attenuation is determined from:

- No. of TLVs $= \log 10 \left(\frac{1}{B}\right)$

- IAEA Report 47 gives the TVLs for a range of megavoltage X ray energies in concrete (density 2350 kg·m–3)

FACTORS USED IN CALCULATIONS

	Co-60[a]	4 MV[b]	6 MV[b]	10 MV[b]	15 MV[b]	18 MV[b]	20 MV[b]	24 MV[b]
TVL for concrete (density 2350 kg · m^{-3}) (in mm)								
Primary beam gamma/ X rays	218	290	343	389	432	445	457	470
Leakage gamma and X rays (90°)	218	254	279	305	330	330	343	356
TVL for steel (density 7800 kg · m^{-3}) (in mm)								
Primary beam gamma/ X rays	71	91	98	105	108	111	111	107
Secondary beam gamma/ X rays	69	79	80	85	87	87	88	89
TVL for lead (density 11360 kg · m^{-3}) (in mm)								
Primary beam gamma/ X rays	41	53	55	56	57	56	55	52

SECONDARY BARRIERS: LEAKAGE

$$B_L = \frac{1000 P d_s^{\,2}}{WT} \qquad (8)$$

where

P is the design dose limit;
d_s is the distance from the isocentre to the point of interest in m;
W is the workload;
T is the occupancy factor.

SECONDARY BARRIERS: SCATTER

$$B_p = \frac{P d_{sca}^2 d_{sec}^2}{aWT(F/400)} \qquad (9)$$

where

P, W and T have the same meaning as in Eq. (8).

d_{sca} is the distance from the radiation source to the patient, in m.

d_{sec} is the distance from the patient to the point of interest, in m.

a is the scatter fraction defined at d_{sca}. The scatter primary ratio (a) is dependent on the energy of the X ray beam and the scattering angle. These data are tabulated per 400 cm^2 of irradiated field area for ^{60}Co, 6, 10, 18 and 24 MV X ray beams in Table 5 [2, 20].

F is the field area incident on the patient, in cm^2.

SECONDARY BARRIERS: SCATTER

$$B_w = \frac{P d_w^2 d_r^2}{\alpha A W U T} \qquad (10)$$

where

d_w is the distance from the radiation source to the scattering surface (wall), in m;

d_r is the distance from the scattering surface (wall) to the point of interest, in m;

α is the wall reflection coefficient, which depends on the wall material, scattering angle, and beam energy (Tables 6 and 7 give reflection coefficients from concrete);

A is the field area projected on the scattering surface (wall), in m^2.

Two Source Rule

- Calculate the Barrier thickness for leakage and scatter independently
- Compare the two thicknesses
- If similar, take the larger and add one HVL
- Otherwise just take the larger

Instantaneous Dose Rate (IDR)

The barrier thickness required to reduce the IDR to an acceptable level on the far side of the barrier is determined as follows. The attenuation required B_{IDR} is given by:

$$B_{IDR} = \frac{P_{IDR}(d + SAD)^2}{DR_0}$$

Wall thicknesses determined for primary barriers will be more than adequate to shield against leakage and scattered radiation and no further calculations are required.

Instantaneous Dose Rate (IDR)

$$B_{IDR} = \frac{P_{IDR}(d + SAD)^2}{DR_0}$$

B_{IDR} is the thickness required in m

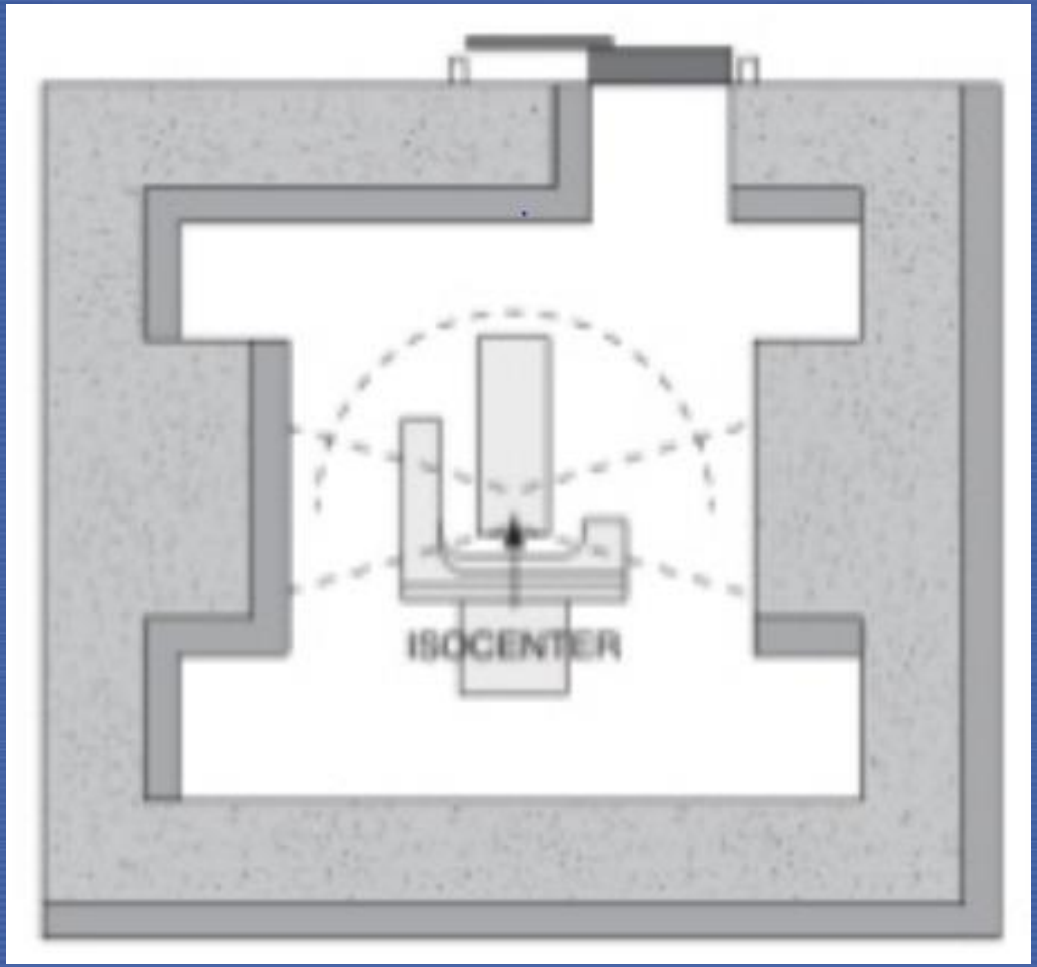
P_{IDR} is the instantaneous design dose limit, in Sv·h–1;

d is the distance from the isocenter to the point of interest on the far side of the barrier, in meters;

SAD is the source–axis (isocenter) distance (usually 1 m for linear accelerators);

DR_0 is the dose rate at the isocenter (1 m), in Gy·h–1.

Direct-Shielded Door



Mazes

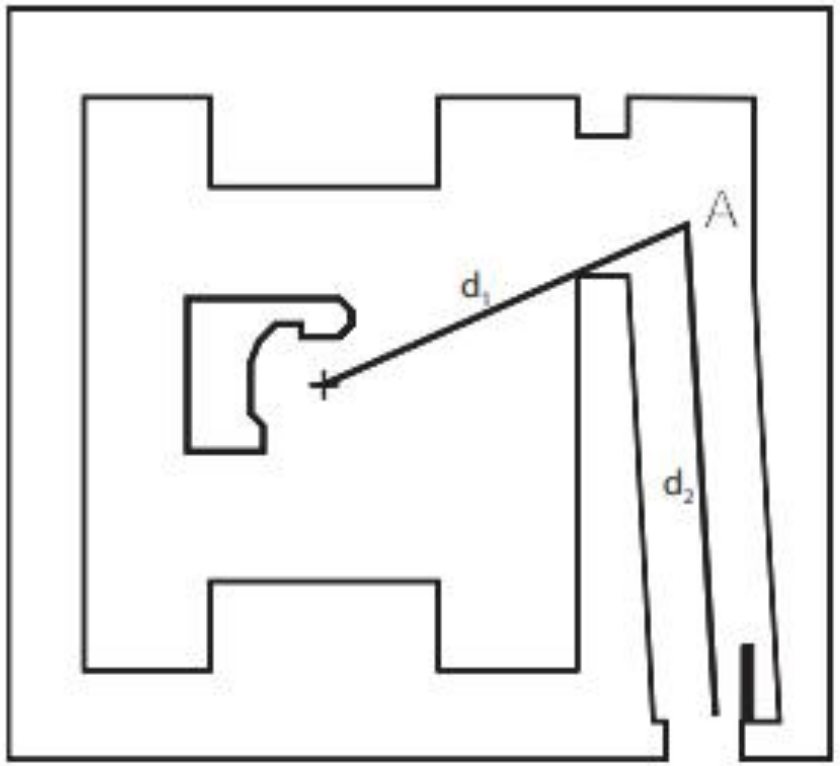


FIG. 8. A typical accelerator room with a maze, showing the distances used to determine the capture gamma dose.

Facility Roof Shielding

- The roof section that can be struck directly by the radiation beam must be a primary barrier and the formulas used to determine the required thickness of material are the same as those in previous slides.

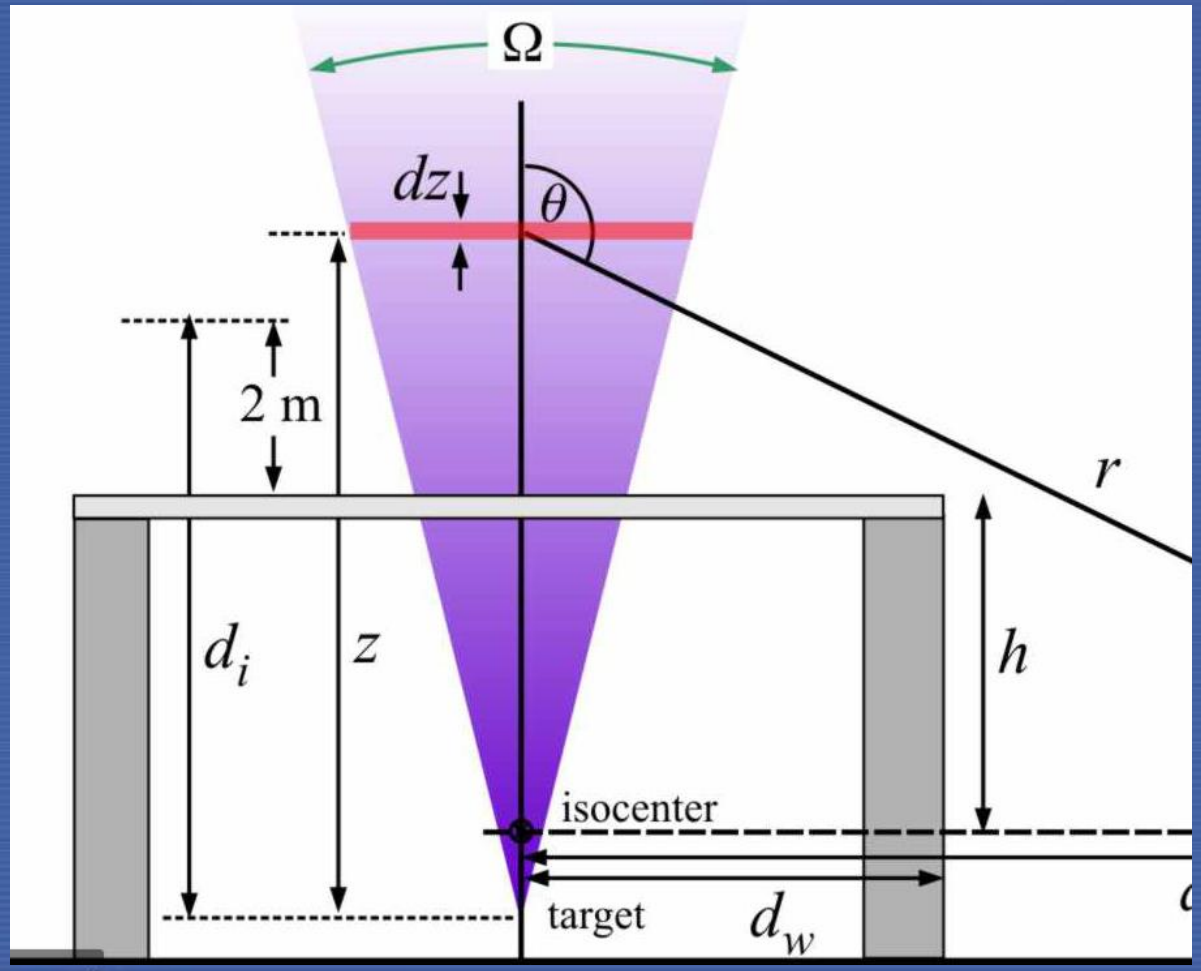
- The design dose limit for the roof will depend on the location of the linear accelerator vault, and what is above (i.e. offices or an unoccupied roof space)

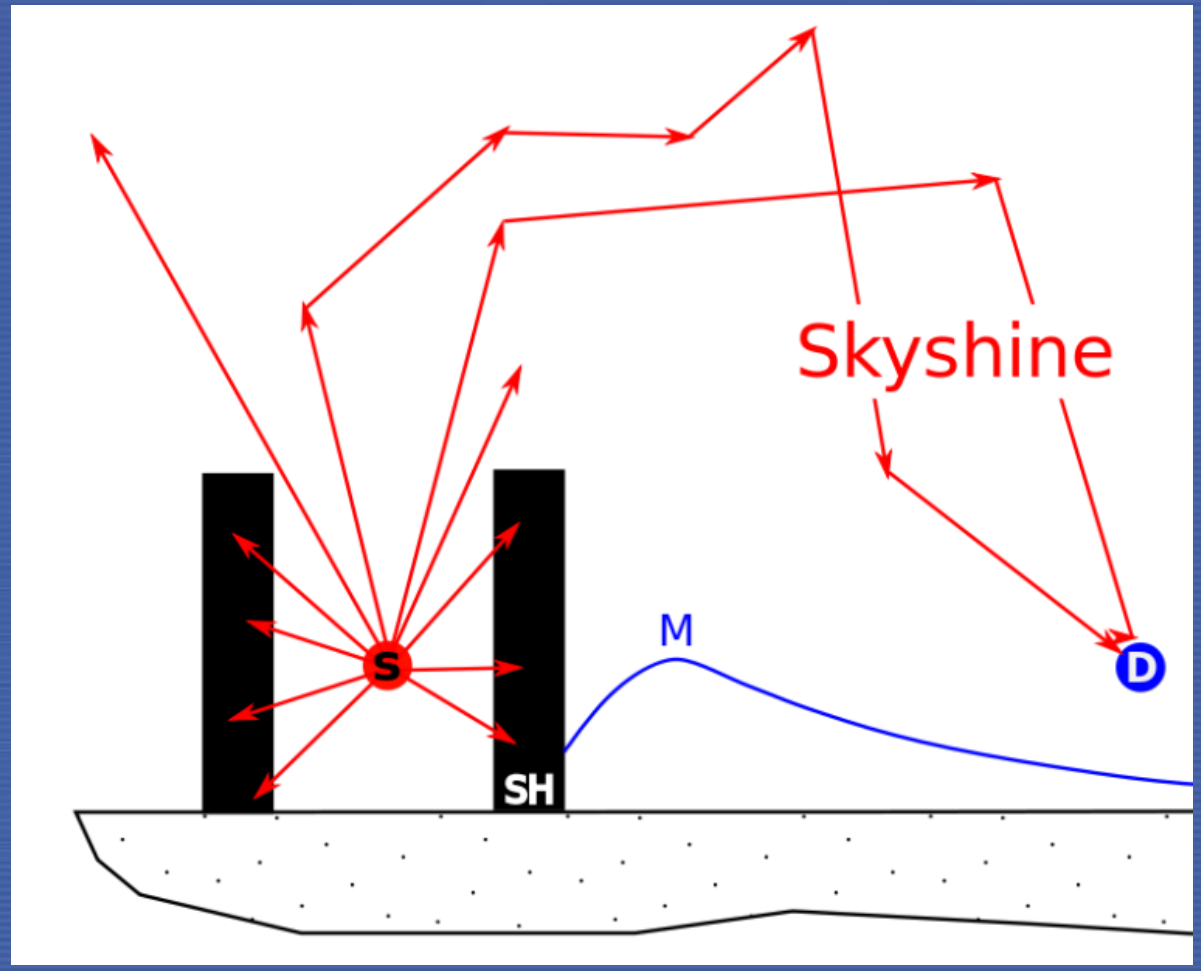
Facility Roof Shielding

- If it is a single-story building, then the one consideration may be the limitation of access to the roof space with a fence and locking the gate.

- However, if the roof shielding is overlooked or disregarded, then the effect of skyshine must be considered. Skyshine may result in the irradiation of nearby buildings.

Facility Roof Shielding





Neutron Shielding

- A concern for 15MV/18MV beams
- No neutron concern with electrons
- Concrete shielding due to high hydrogen content
- High dose at maze door
- Material to capture: Boron

Quiz-Questions

1. What are the two shielding design limits that must be met?
2. For 360 degree gantry rotation how many primary barriers are there?
3. What is the two source rule used for? Describe it.
4. If the roof is unoccupied, what are the shielding considerations that must be made?

Quiz-Answers

1. What are the two shielding design limits that must be met?

   Instantaneous dose rate and weekly dose.

2. For 360-degree gantry rotation how many primary barriers are there?

   Four

3. What is the two source rule used for? Describe it.

   Barrier thickness for secondary barriers.

4. If the roof is unoccupied, what are the shielding considerations that must be made?

   Skyshine, proper restriction and signage

Exercise 5: Shielding Worksheet

This exercise should take 60 minutes +

Summary : Questions and Answers

Staffing and Training Quiz-Questions

1. Which roles are listed explicitly on the license?
2. Which role is responsible for developing and implementing the QA program?
3. Which role serves as a liaison to the regulatory agency?

Staffing and Training Quiz-Answers

1. Which roles are listed explicitly on the license?

RSO, Radiation Oncologist, Medical Physicist

2. Which role is responsible for developing and implementing the QA program?

Medical Physicist

3. Which role serves as a liaison to the regulatory agency?

RSO

Facility Construction Quiz-Questions

1. On what level are LINAC vaults typically constructed, and why?
2. Where should ductwork/conduits pass through and what shape should they take? Why?
3. When replacing a LINAC the previous shielding may be sufficient if this is true?
4. For 18MV LINACs, how much additional concrete is required to shield photo-neutrons?

Facility Construction Quiz-Answers

1. On what level are LINAC vaults typically constructed, and why?

   Ground level or basement

2. Where should ductwork/conduits pass through and what shape should they take? Why?

   Secondary barrier at an angle

3. When replacing a LINAC the previous shielding may be sufficient if this is true?

   Equal or lesser energy

4. For 18MV LINACs, how much additional concrete is required to shield photo-neutrons?

   None

Shielding Calculations Quiz-Questions

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   Skyshine, proper restriction and signage