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Radiation Protection At Synchrotron Radiation Facilities

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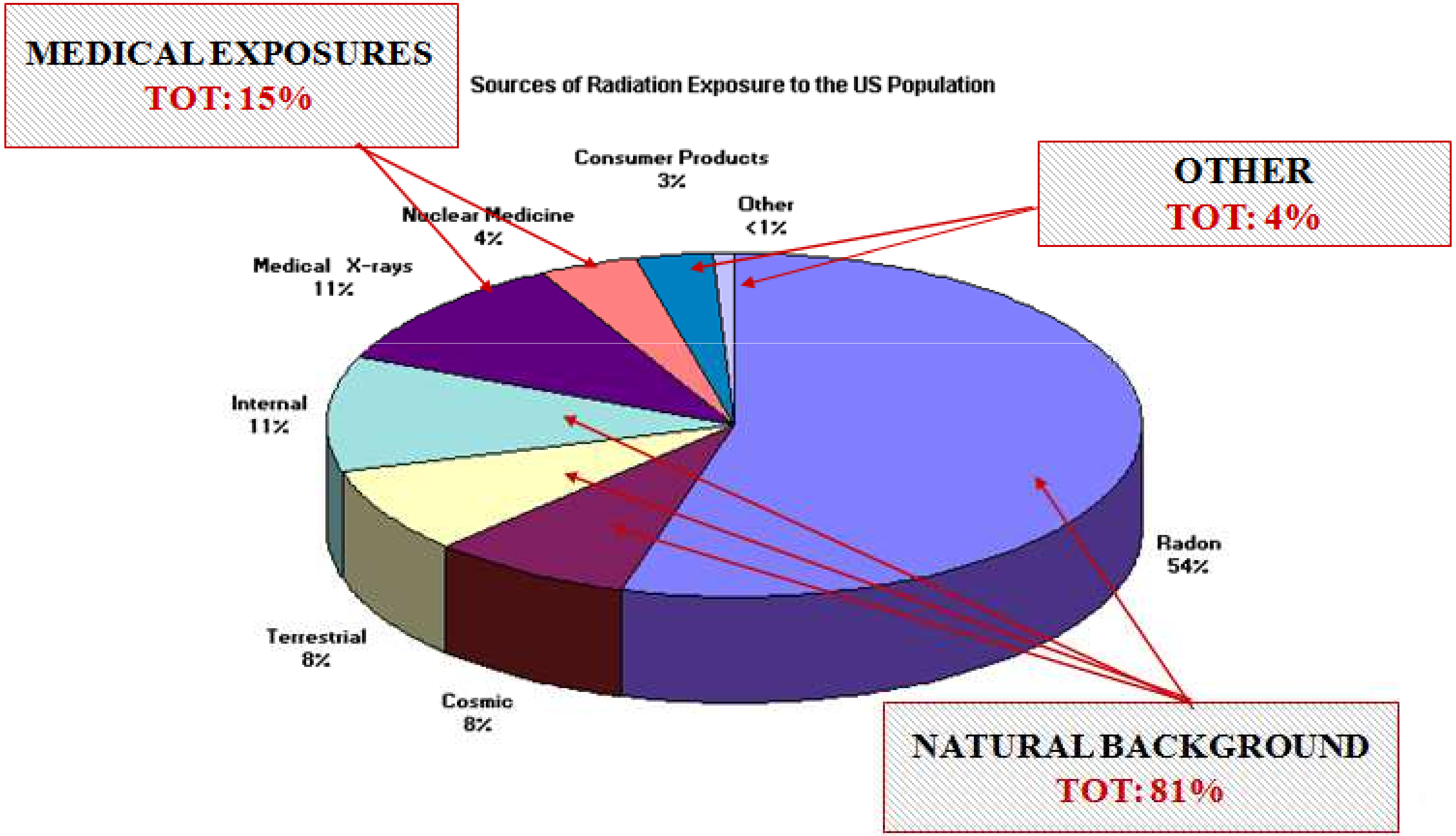
Outline

- **Introduction to Radiation shielding**
- **Radiation Sources at the Synchrotron Facilities**
- **Calculational Tools and Procedures**
- **Linac and Synchrotron Ring Shielding Design**
- **Gas Bremsstrahlung Source**
- **Beam stop**
- **Labyrinth**
- **Personal Safety System**

Average Population Exposure



Limiting Exposures

basic ways to limit exposure:

Time: limiting or minimizing the exposure time will reduce the dose from the radiation source.

Distance: Radiation intensity decreases sharply with distance, according to an inverse square law.

Shielding: Barriers of lead, concrete, polymers or water give effective protection from radiation formed of energetic particles such as gamma rays and neutrons.

glovebox

Dose Limits

Annual equivalent dose at any point in the facility even immediately outside the shield should be below

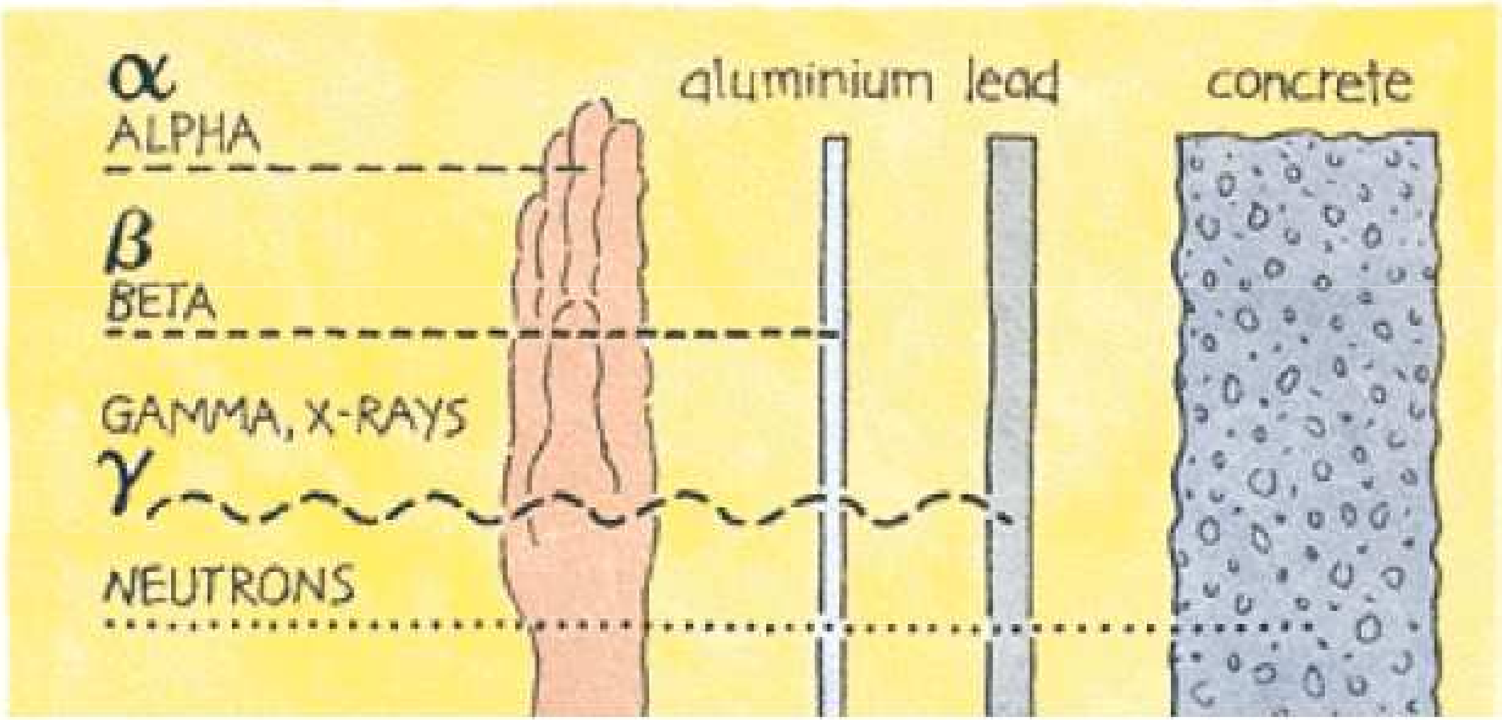
1 mSv (0.5 μSv/hour)

	Public	Workers
Effective dose (mSv/year)	1	20
Lens of the eye (mSv/year)	15	150
Skin (mSv/year)	50	500
Hands and feet (mSv/year)	50	500

An assortment of typical radiation doses (in mSv)

Approximate lethal dose ("LD50") if no treatment and given to the entire body in a short period	4,500
Increase in lifetime dose to most heavily exposed people living near **Chernobyl**	430
Radiation level per hour outside the **Fukushima Daiichi** Nuclear Power Station in Japan on 22 March 2011. (11 days after the reactors were damaged)	0.3
Natural background, Boston, MA, USA (per year)(excluding radon)	1.02
Additional annual dose if you live in a **brick** rather than a wood house	0.07
Annual dose in some houses in **Ramsar, Iran**	>130
Received by the colon during a barium enema	15
Received by the **lungs** during a typical chest x ray	0.1
Received by each breast during a typical mammogram	2.8
Dose from a typical set of full-body computed tomography scans	45
Flight crew flying regularly between New York and Tokyo (per year)	9

Protection Against External Exposure



Ionizing Radiation Hazards

- Electron beam loss during different stages of acceleration
- Electron beam loss in different parts of machine
- Radiation from bending magnets and insertion devices

The radiation field from high energy electron loss depends strongly on the electron energy, target material, thickness

Radiation Sources

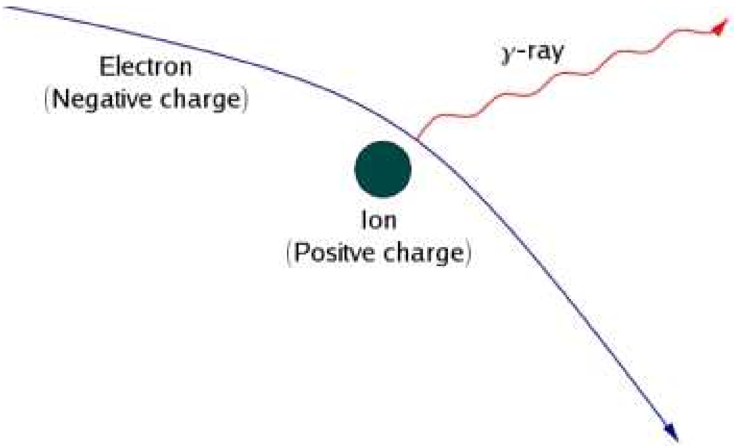
- **Bremsstrahlung**
  - High Energy Photons
    - Gas and Non-Gas
- **Neutrons**
- **Synchrotron radiation**
  - ID and BM
  - Low Energy Xrays
- **Induced activation**

Bremsstrahlung

- Bremsstrahlung is emitted by a high energy electron as it decelerates due to inelastic radiative interaction with the coulomb field of atomic nuclei of the medium.

- High-energy electrons produce Bremsstrahlung when strike residual gas molecules in the vacuum chamber or the accelerator components.

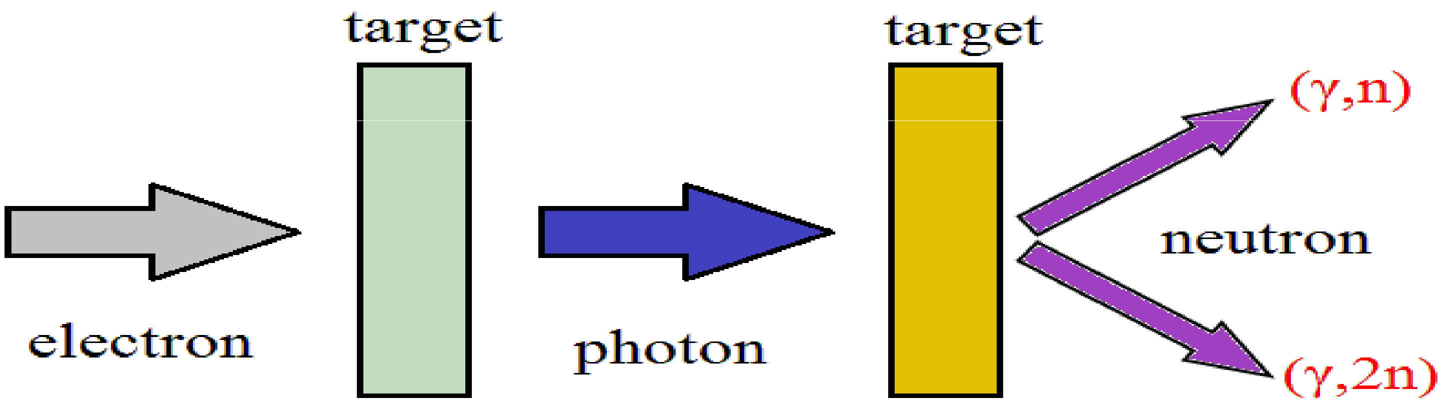
➢ Gas Bremsstrahlung



Neutron Production

- Bremsstrahlung photons subsequently interact with the nucleus of the target material

➢ photonuclear interaction



- neutrons are bounded with the nucleus by binding energy (5-15 MeV), the photon should have energy above the threshold.

Neutron

- **Giant Resonance Neutron**

$7 < E_{ph} < 20$ MeV

Average effective energy of about 2 MeV and emitted isotropically

- **High Energy Neutron**

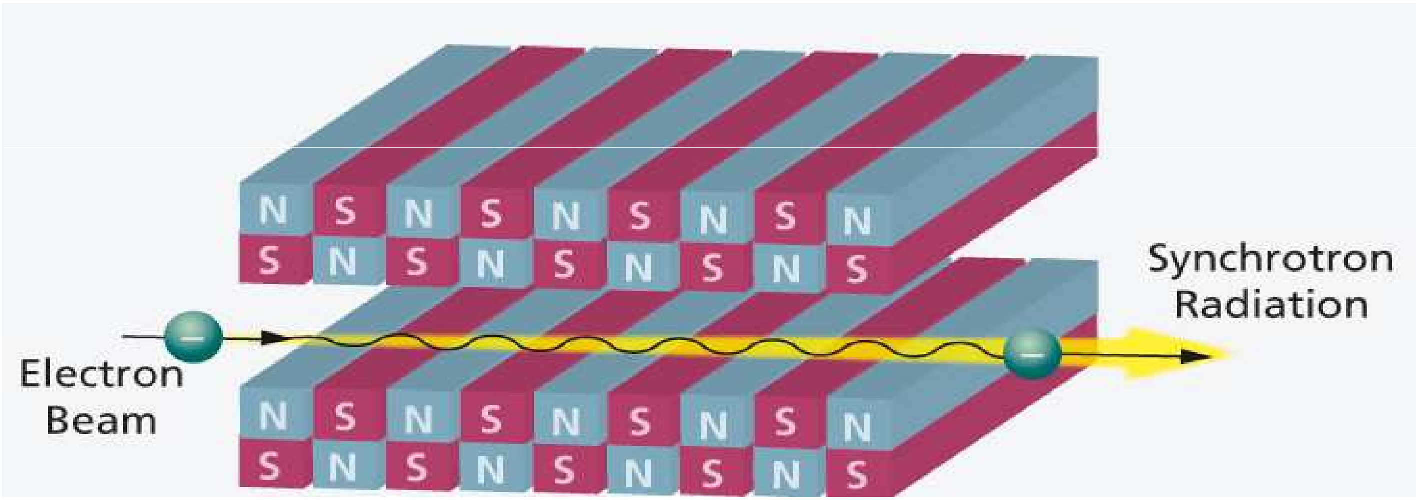
$E_{ph} > 25$Mev

Radiation component that dominates for thick shields

Forward peaked but not as strongly as BRM photons

Synchrotron Light

- Synchrotron radiation is high intensity (kW) and low energy (keV).



- Scattered gas Bremsstrahlung requires far greater shielding thickness than scattered synchrotron radiation.

Induced Activation

- The photoneutron interaction of Bremsstrahlung with materials leads to the radioactivation of accelerator components through neutron emission and the production of radioisotopes.

- The amount of activity depends on the electron energy, beam power, bremsstrahlung production efficiency, and type of material.

Calculational Tools

- **Analytical Methods**

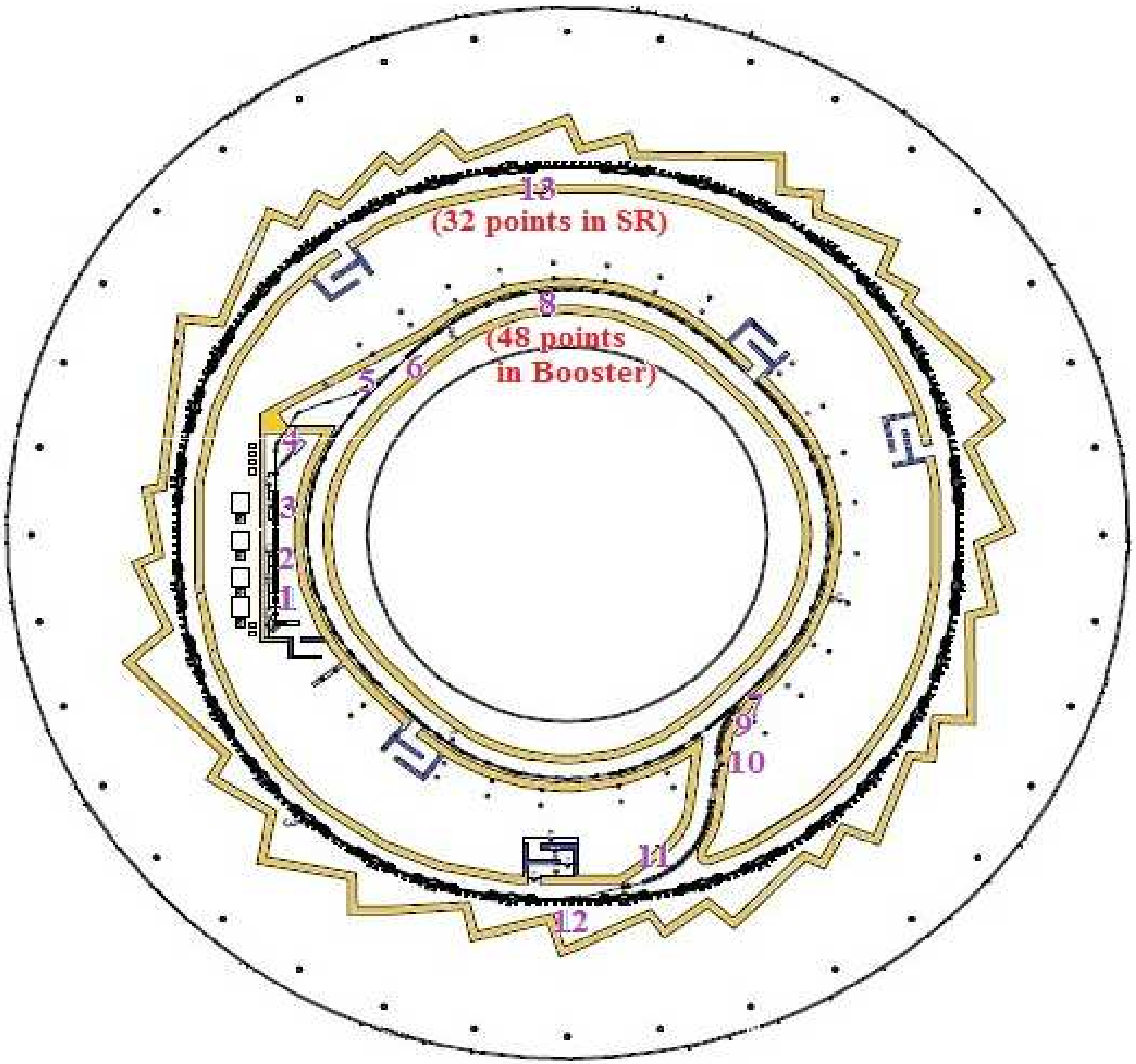
- **Monte Carlo Methods**

➢ FLUKA and MCNPX Monte Carlo codes are capable codes which have been used widely in shielding calculations.

Beam Loss Estimation

- Linac loss points
- Transfer lines loss points
- Synchrotron accelerators loss points

Electron Loss Points



Shielding Materials

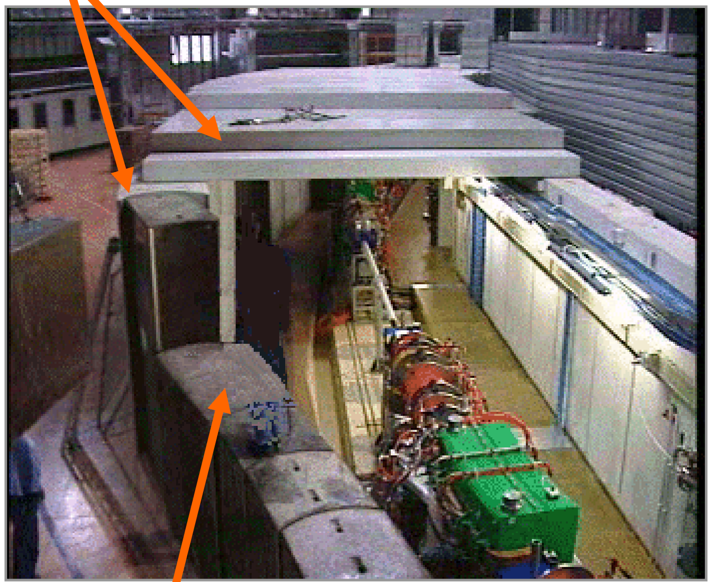
concrete The best compromise to shield mixed radiation fields (gammas + neutrons)

lead Building hutches walls and for local shielding(major gamma radiation).

Tungsten Excellent, but relatively expensive

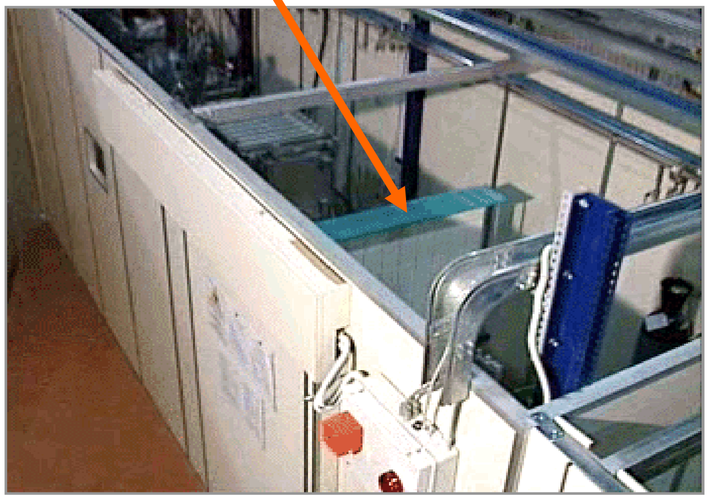
Polyethylene $(CH_2)_n$ Very effective neutron shield.

Ordinary concrete blocks



Heavy concrete blocks

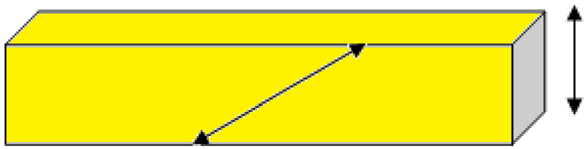
Lead wall



Shielding Thicknesses

Ordinary concrete thickness (m)

	Linac	LTB	Booster	BTS	Storage ring
Outward	1	1	1	1	1-1.3
Inward	1	1	1.2	1.4-1.6	1
Forward	1.6	1.5	1.6-4	1.6-4.4	1.4-1.6
Upward	1	1	1-1.3	1.3	1.1-1.3



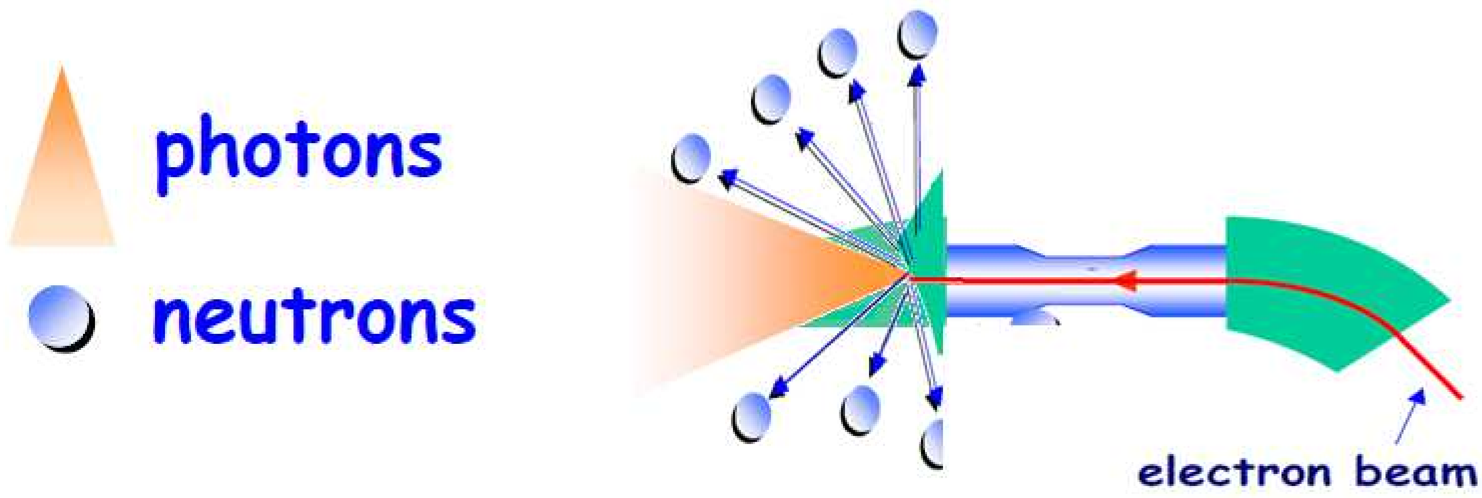
Effective Shielding Thickness

Monte Carlo Simulation for Characterization of

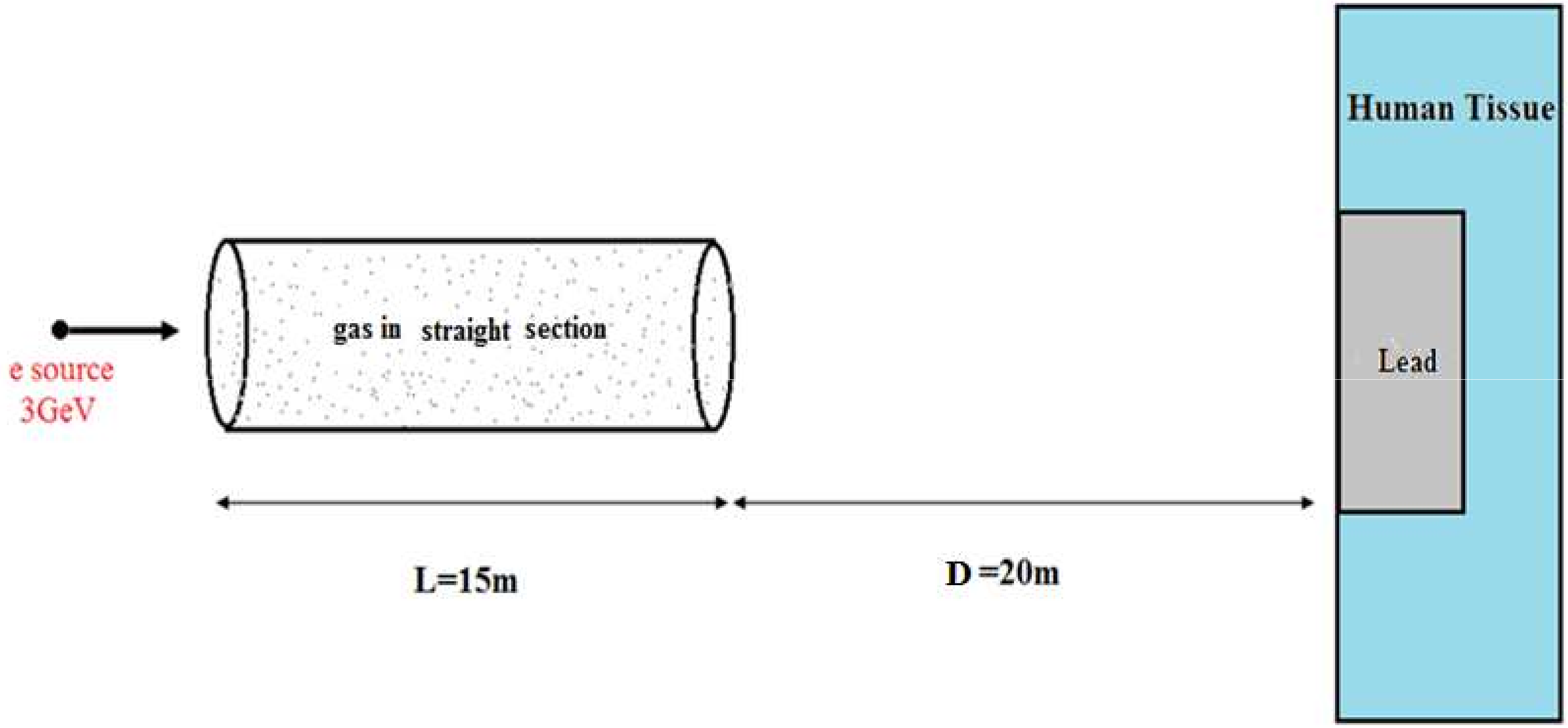
Gas Bremsstrahlung in ILSF IDs

Gas bremsstrahlung in Storage Ring

- 3GeV electron beam
- Cylindrical air target of length 15m at a pressure of 1 atm and 0.1 atm
- Human tissue with and without beam stop in 20 m distance downstream of straight section

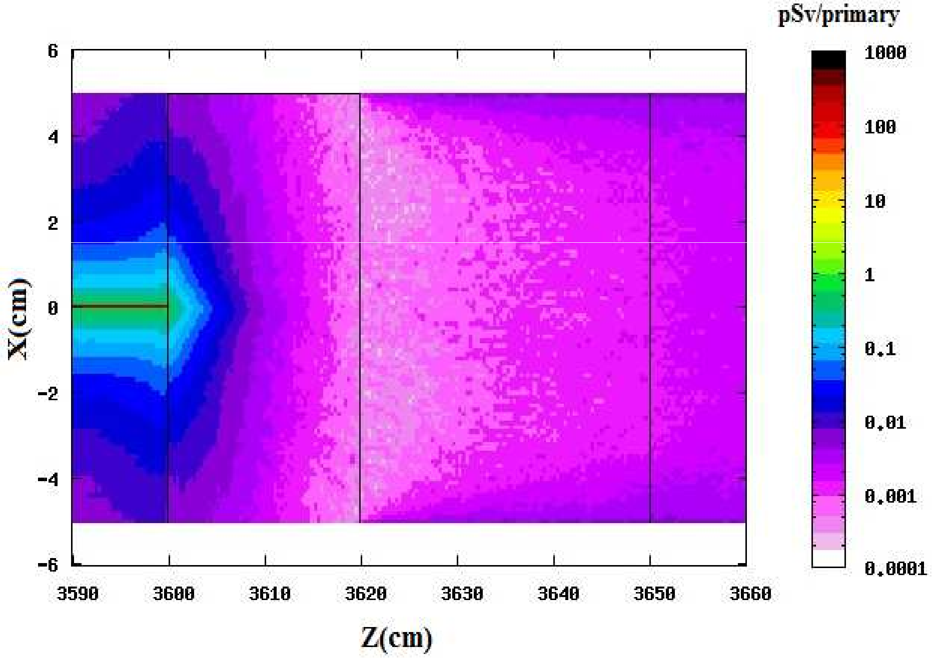


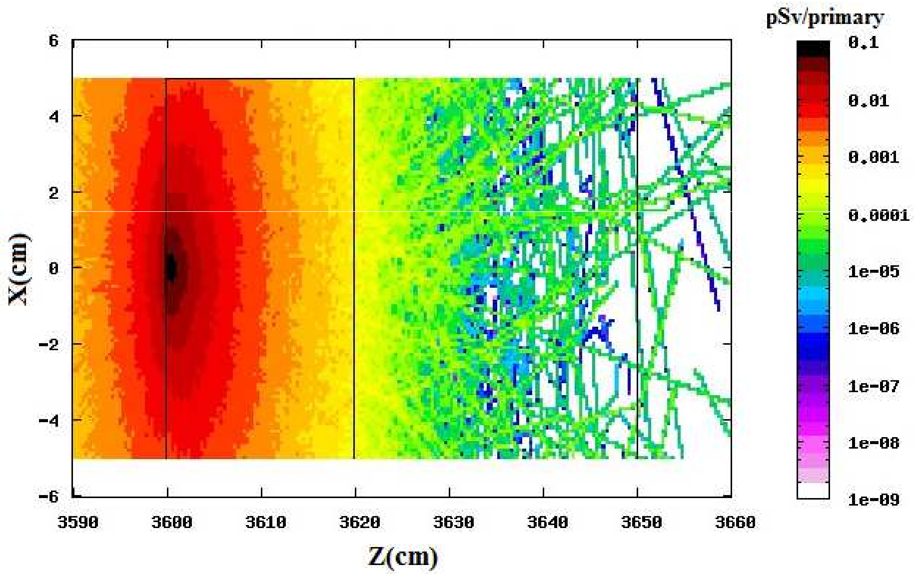
Geometry



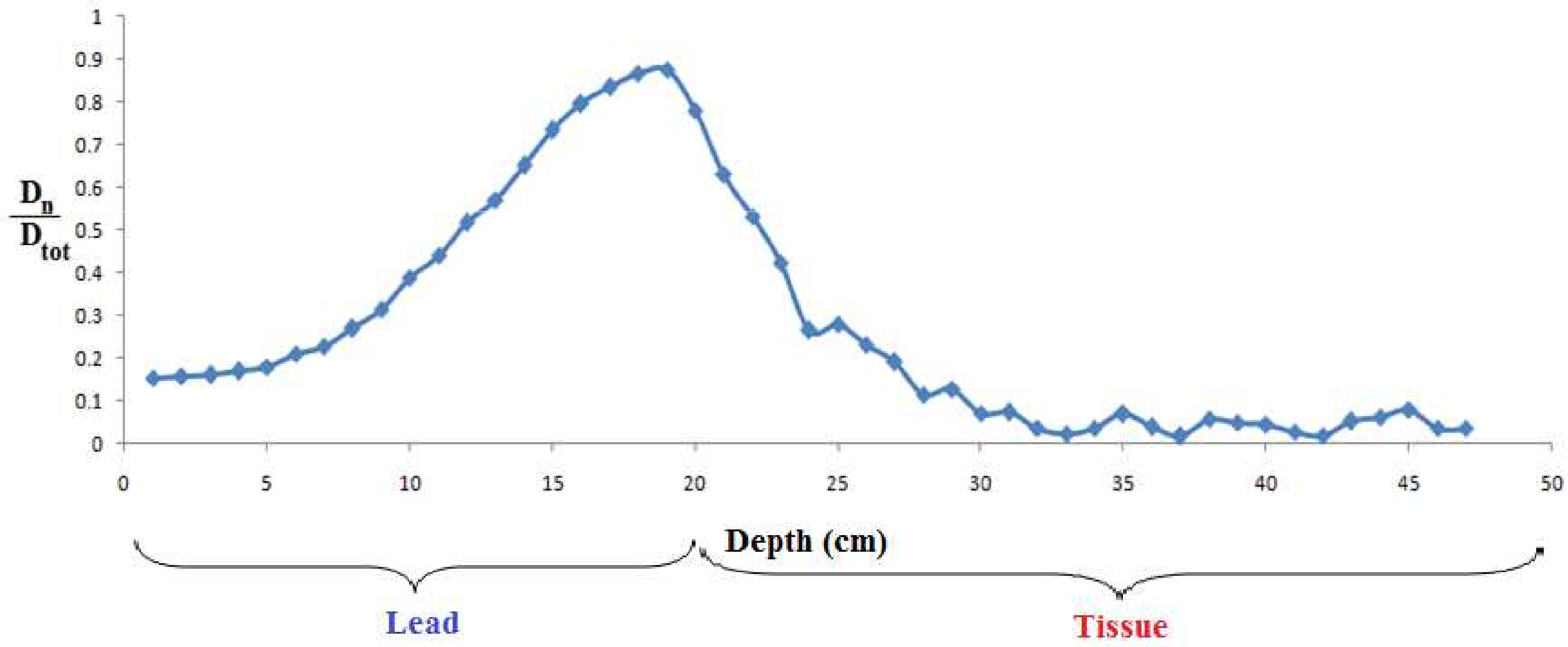
e source
3GeV
gas in straight section
L=15m
D =20m
Human Tissue
Lead

Total and Neutron Dose Equivalent in Tissue and Lead





Neutron Dose Contribution



Gas Bremsstrahlung Spectrum (Rossi Formula)

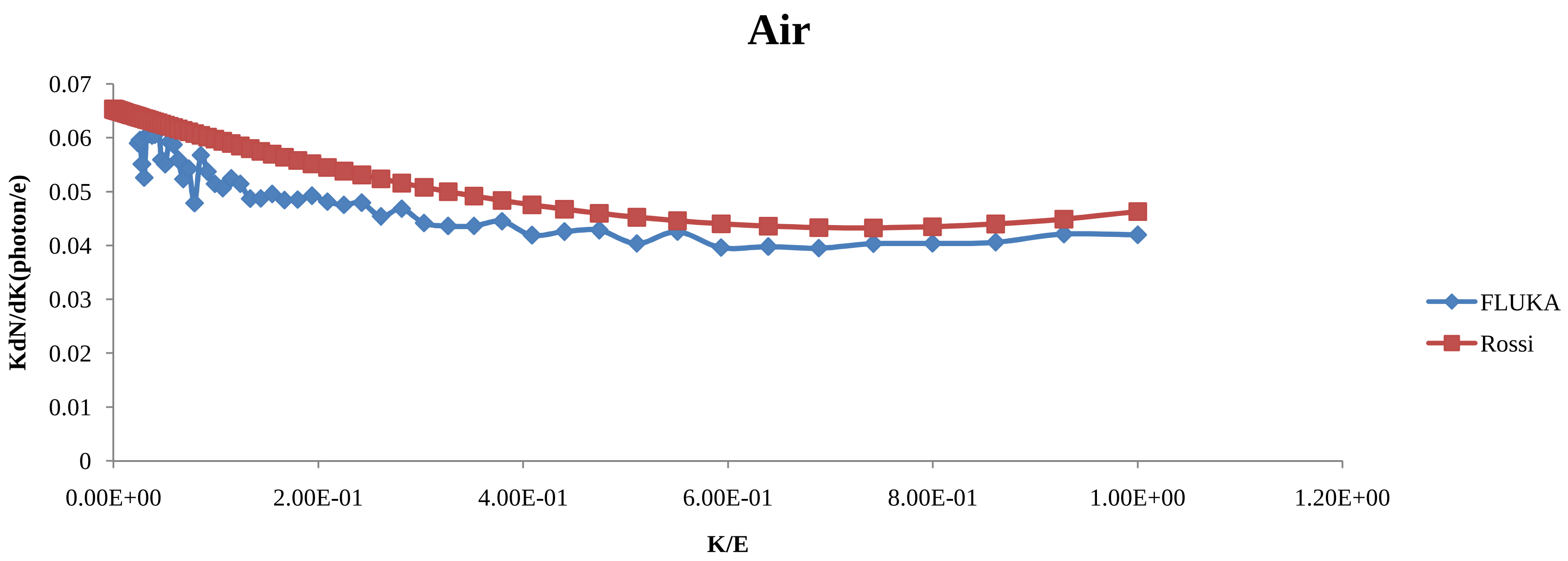
$k\, dN/dk = 4\, \alpha\, r_e^2\, (2N_A/A)\, Z(Z+l)\, f(v,Z)$

$f(v,z) = (v^2 - 4v/3 + 4/3)\ \ln(183\, Z^{-1/3}) + (l-v)/9$

α is fine structure constant = l/137; r_e is classical electron radius = 2.82×10^{-13} cm; N_A is the Avogadro constant

dN/dk is the number of photons within dk about k when one electron with energy E passes through an air path of 1 g cm $^{-2}$ thick.

FLUKA and Rossi



Dose-Pressure

- Ferrari

$$\dot{D} = 2.5 \times 10^{-27} \left(\frac{E_0}{m_0 c^2}\right)^{2.67} \frac{L}{d(L+d)} I \frac{P}{P_0}$$

- Rindi

$$\dot{D} = 1.7 \times 10^{-24} E^{2.43} I L \frac{P}{P_{atm}}$$

L = effective length of the straight path I = beam current in e/s (2.5 ×1018 electrons/s for 400 mA), E = electron beam energy in MeV, P = operating pressure in the vacuum chamber in nTorr, and P_0 = 1 nTorr.

d is nominally taken as 20 meters

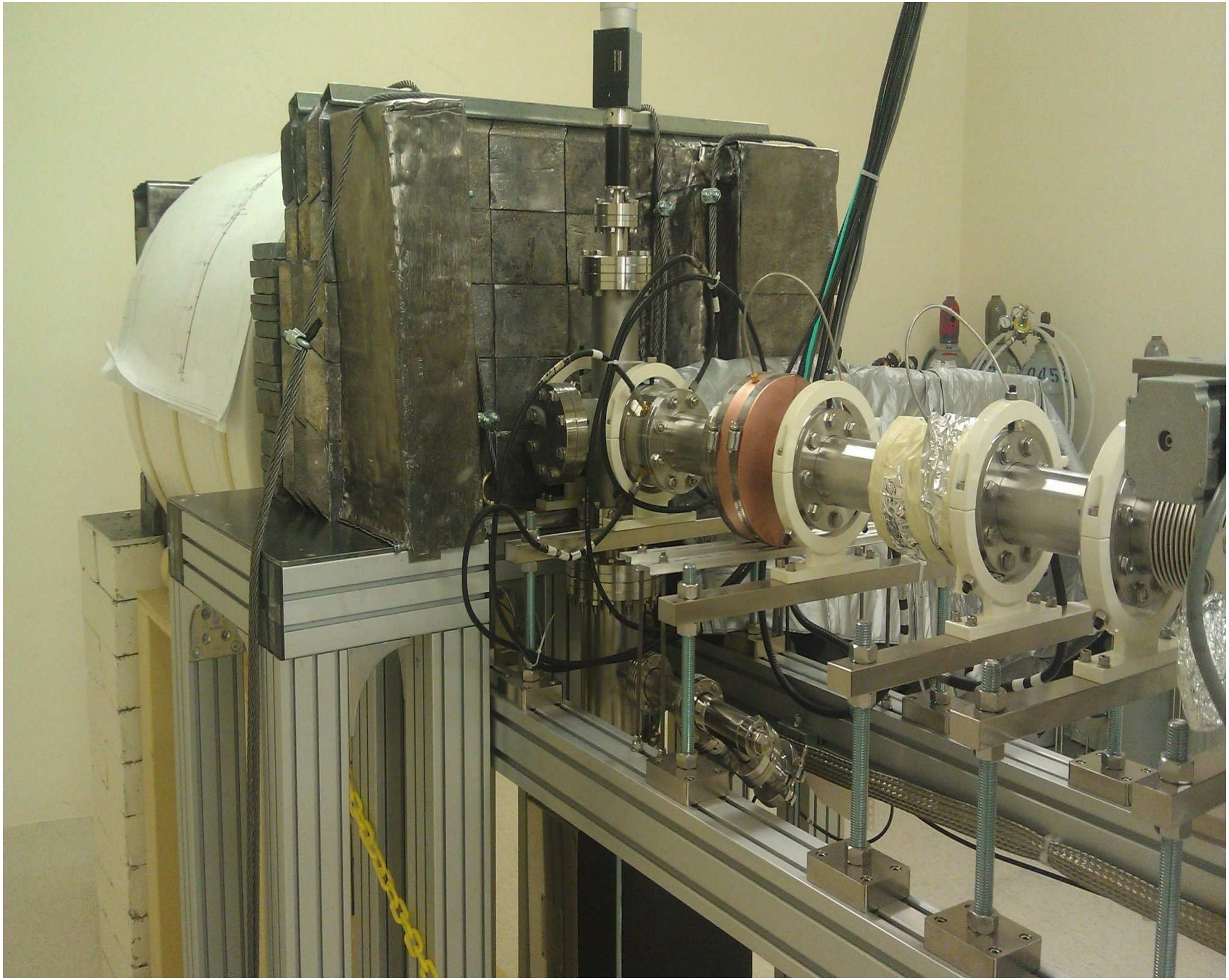
Dose-Pressure

P(Torr)	**P_0(Torr)**	**D(pSv/e) Ferrari**	**D(pSv/e) Rindi**	**D(pSv/e) FLUKA**
760	1.00 E-09	1.31E+2	4.98E+1	1.62 E+1 ± 4%
76	1.00 E-09	1.31E+1	4.98E+00	16.8 E+1 ± 7%

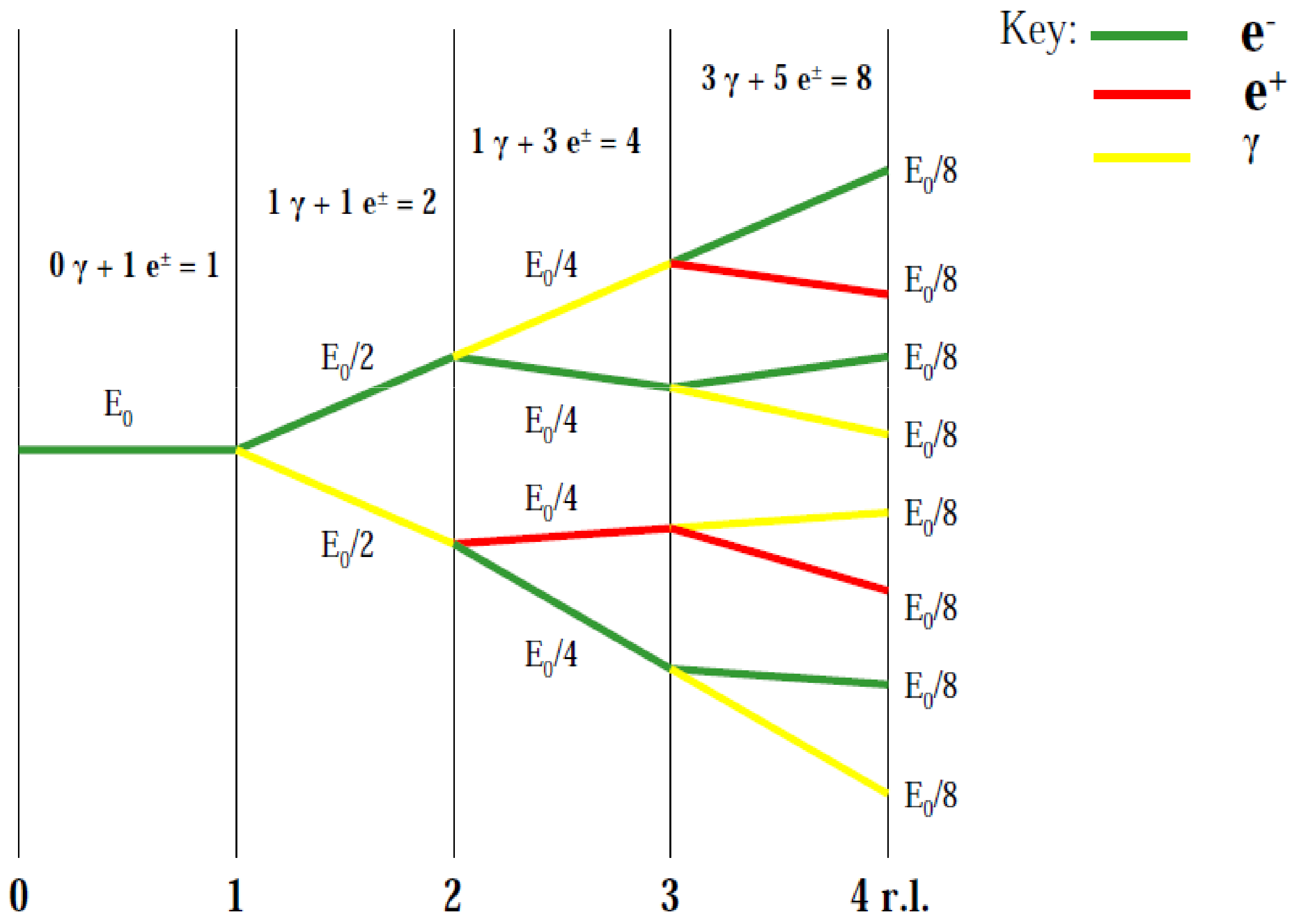
Shielding Calculation for ILSF Beam Stop, Analytical Method and Monte Carlo Simulation

Beam Dump

- Beam Stop controls the beam in synchrotron accelerator
- It is assumed all electrons are lost in these parts.
- Therefore it is the worst case in radiation shielding considerations.
- Bremsstrahlung radiation is produced when electron beam strikes stopper.
- If the bremsstrahlung photon energy is high enough, gas bremsstrahlung can produce neutrons via photo-neutron interaction.



Electromagnetic shower



Electromagnetic shower

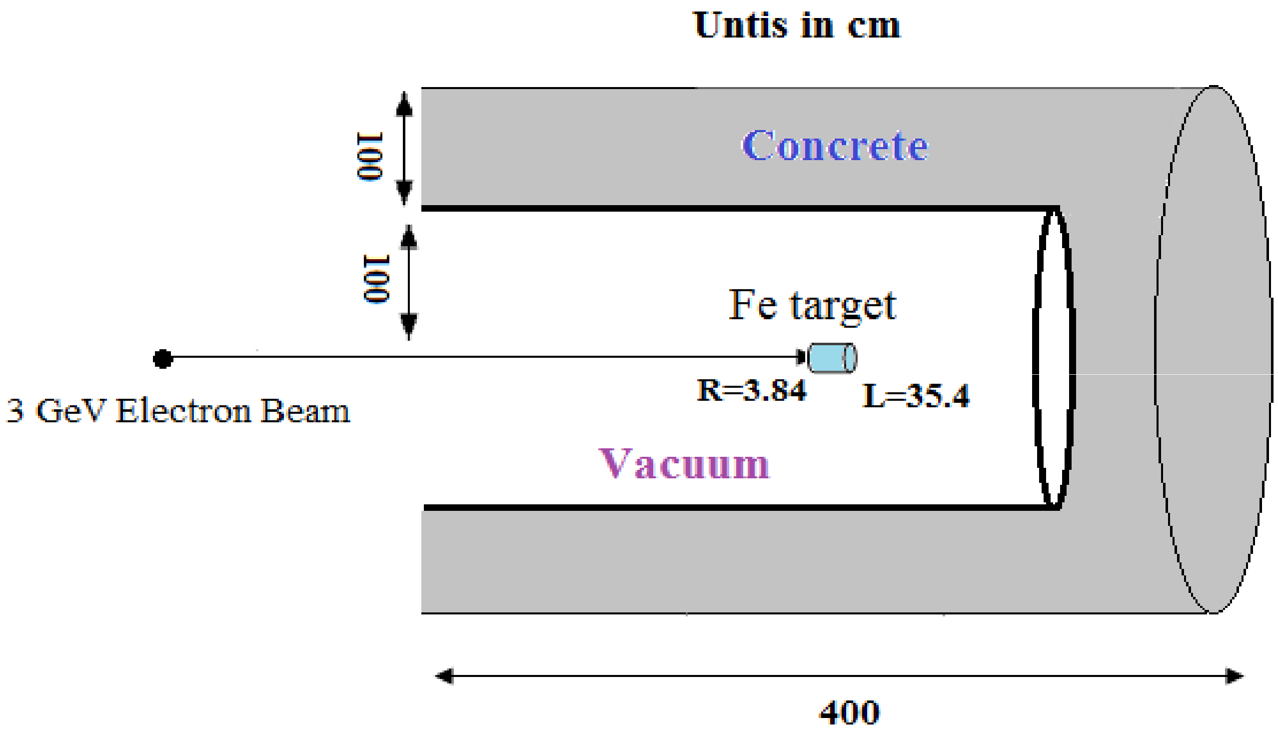
- The distance needed to reduce, by radiation, the average electron's energy to 1/e of its original value is called a radiation length, X_0. In the high-energy limit $$X_0(\mathrm{g/cm^2}) = \frac{716A}{Z(Z+1)} \frac{1}{\ln\left(\frac{183}{Z^{1/3}}\right)},$$

- There is also a transverse development of the shower due to Coulomb scattering of the electrons and Compton scattering of the photons. This is described by the Moliere length, X_m $$X_m = X_0 \frac{21.2}{E_c(\mathrm{MeV})}.$$

The Optimums

Material	Density(g/cc)	Z(eff)	A	Critical Energy(MeV)	Radiation Length(cm)	Molier Length(cm)
Aluminum	2.702	13	**26**	**56.33**	**8.68**	**3.267**
Copper	8.96	29	**63**	**26.49**	**1.88**	**1.50**
Iron	7.874	26	**56**	**29.41**	**1.77**	**1.28**
Concrete	2.35	12.2		**59.7**	**9.21**	**3.87**
air	0.001	6.83	**29**	**99.56**	**84888.64**	**18075.92**

Geometry

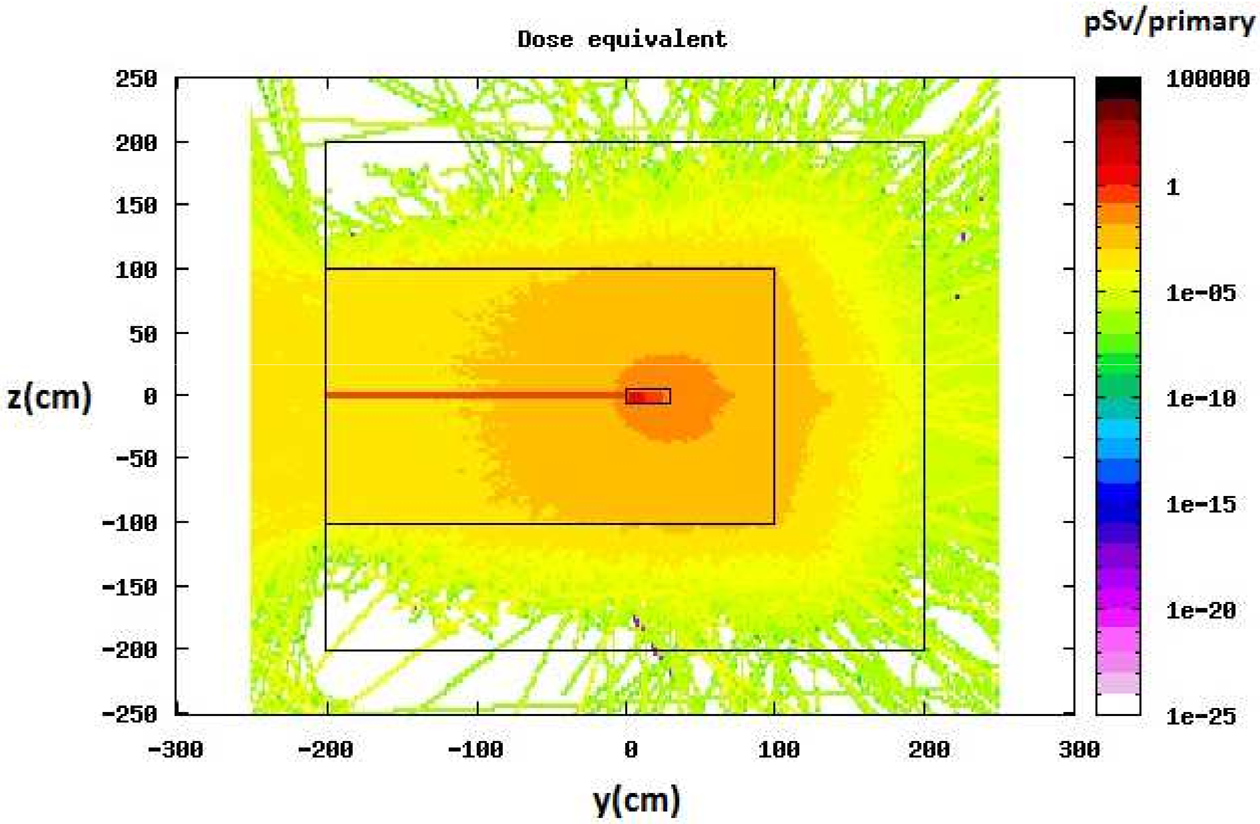


Beam energy: 3 GeV

Concrete thickness: 100 cm

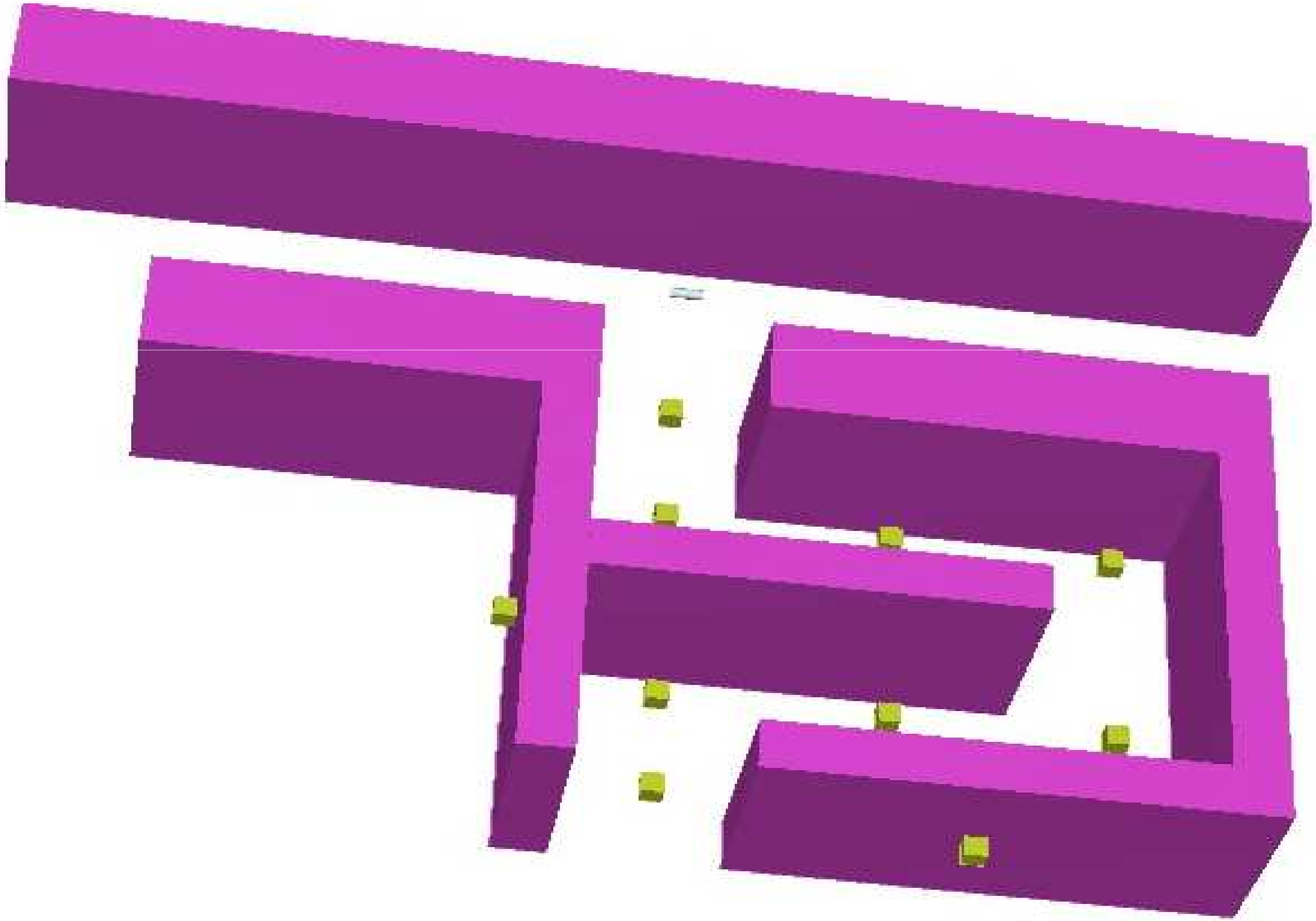
Material of target: Iron

Dose Equivalent

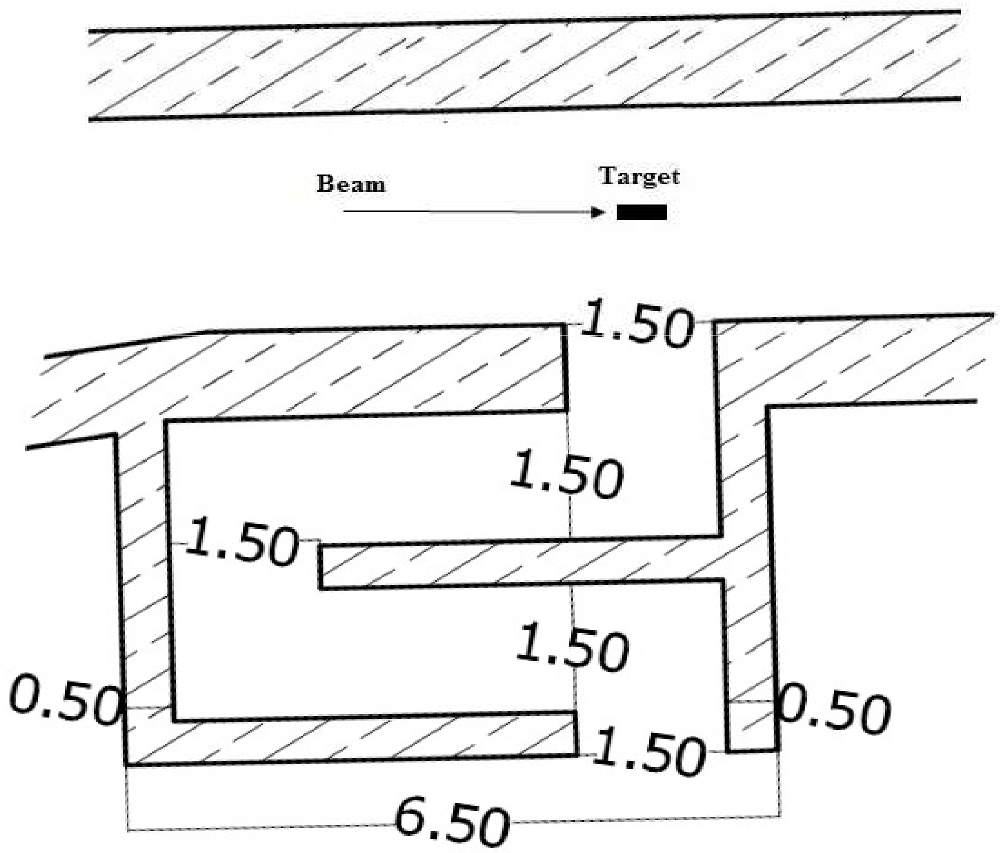


Investigation of Radiation Streaming and Shielding Calculations for ILSF Maze

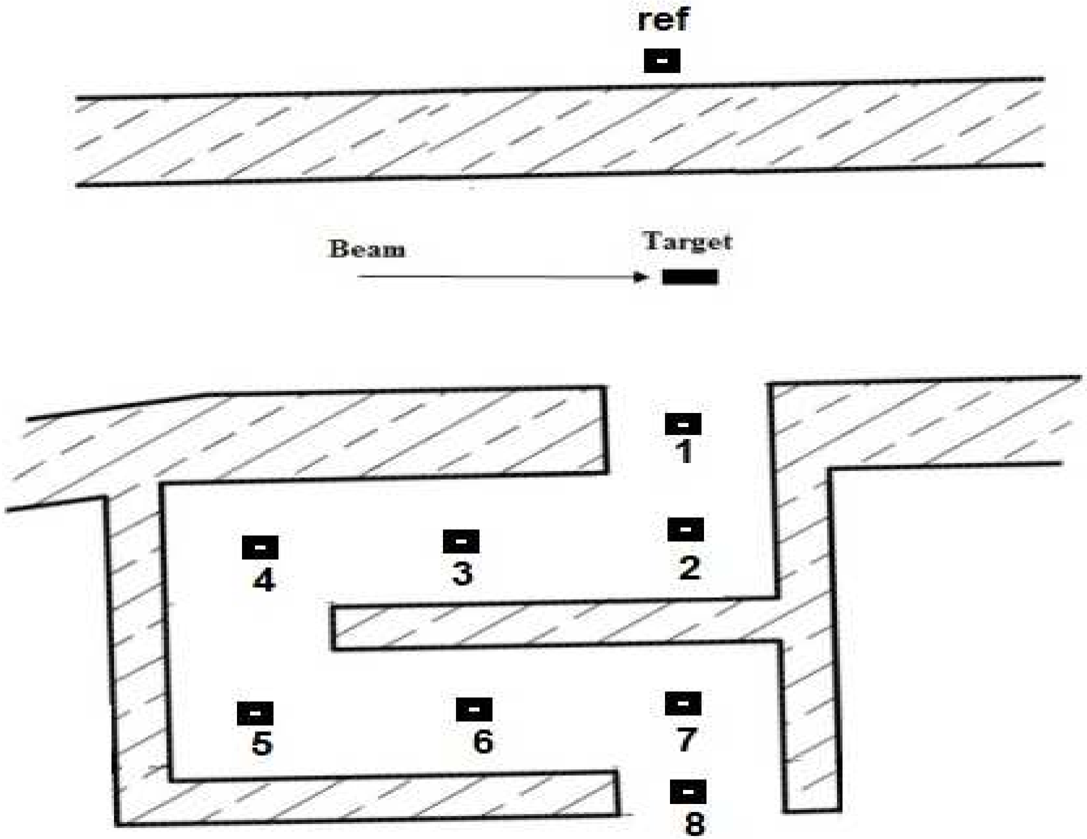
Simulated Geometry



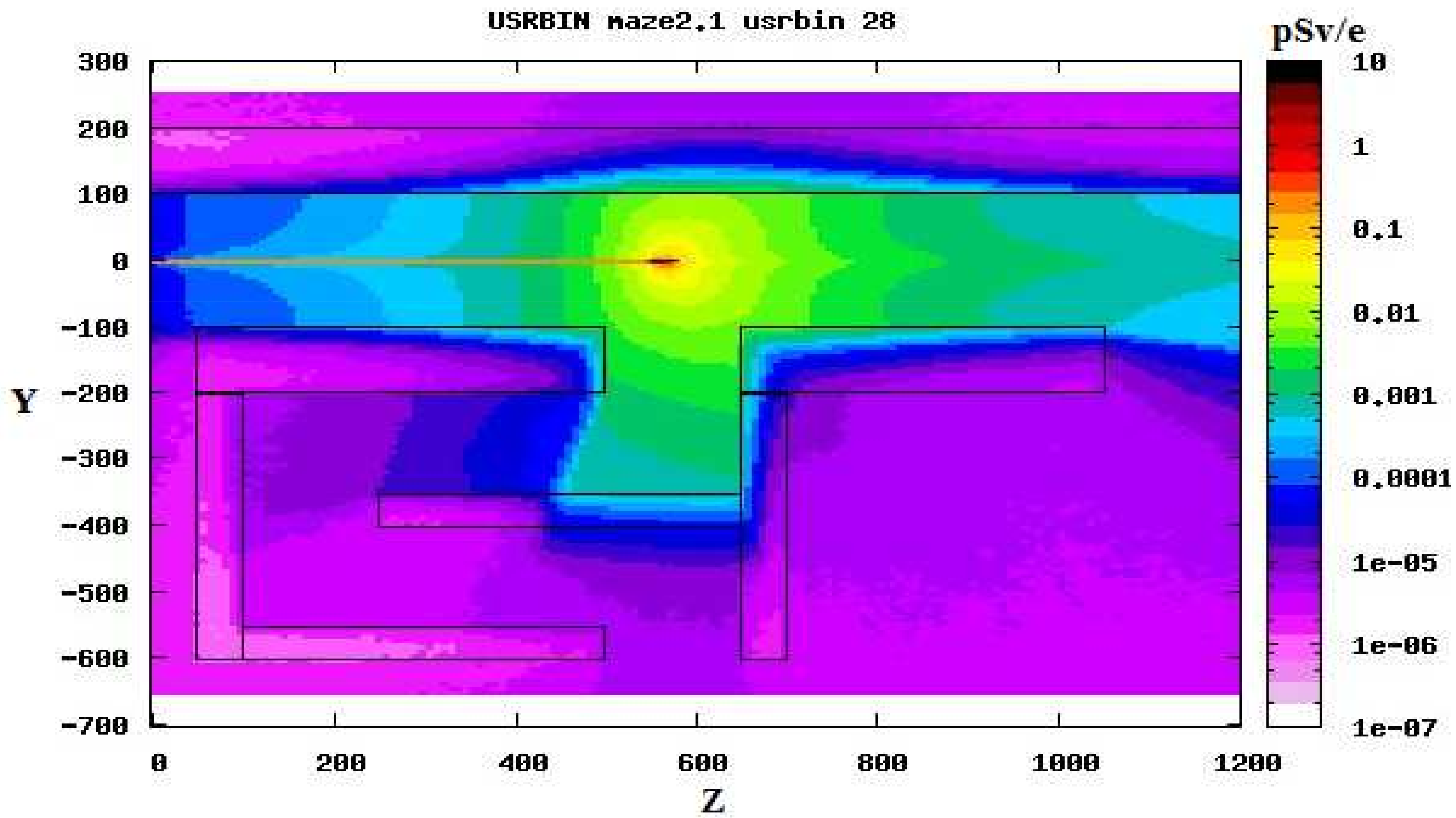
Width and Thickness

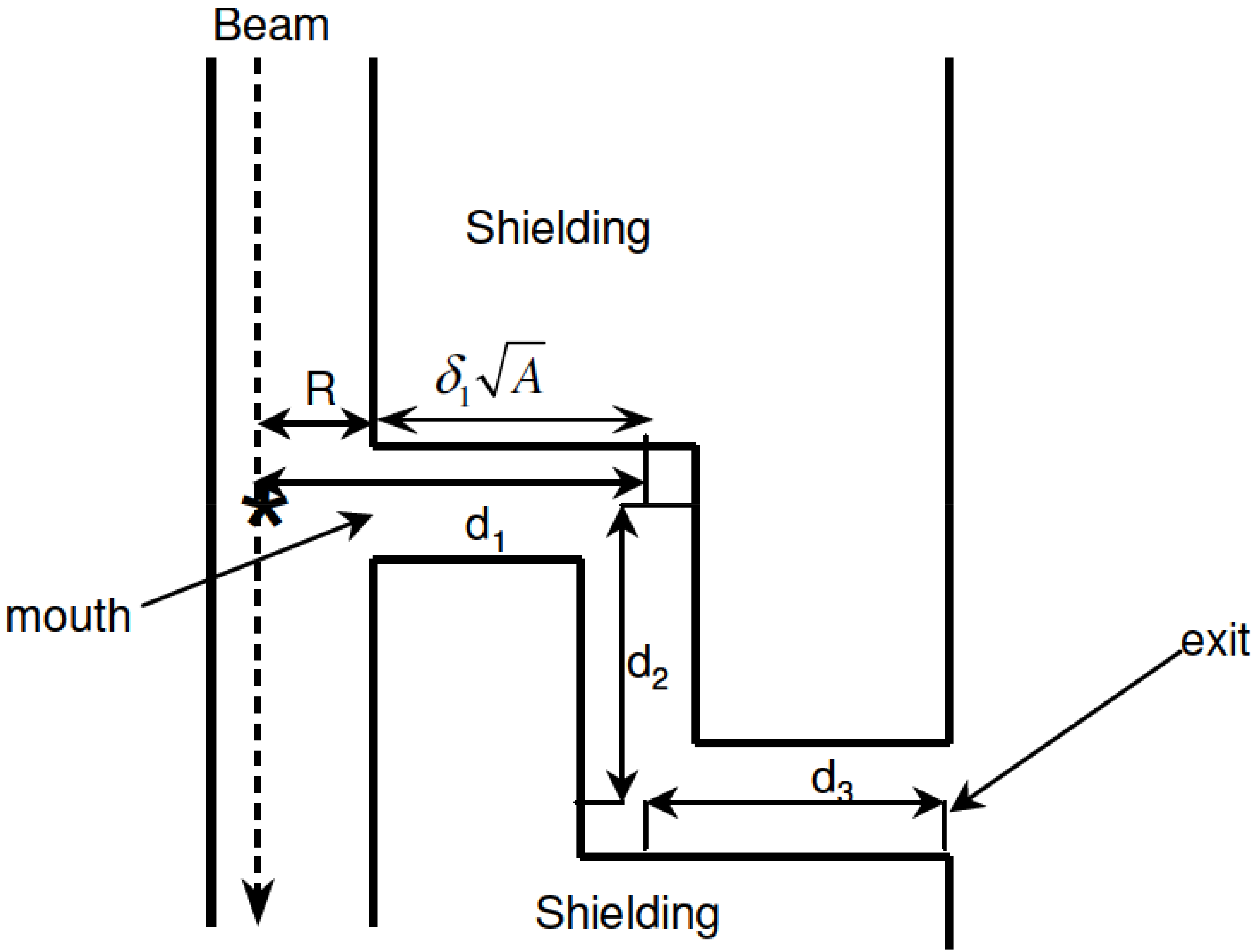


Detectors



Total Dose equivalent

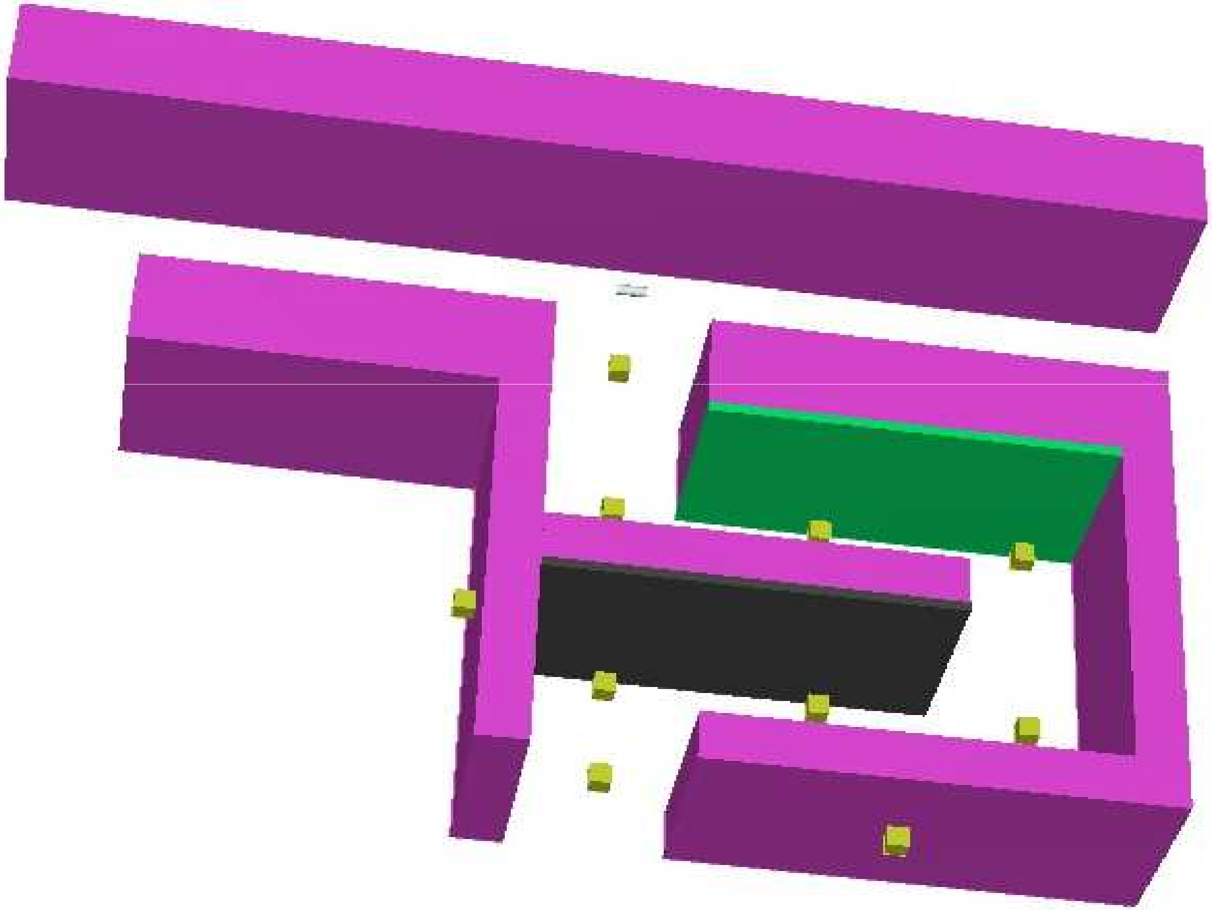



Beam
Shielding
R
$\delta_1\sqrt{A}$
d_1
mouth
d_2
exit
d_3
Shielding

Photon and Neutron Doses At several Locations Along ILSF Maze

Location	**Photon**(pSv/e)	**Neutron** (pSv/e)	**Total** (pSv/e)
Det. 1	6.58E-03	2.09E-03	8.67E-03
Det. 2	8.45E-04	4.03E-04	1.25E-03
Det. 3	6.77E-06	2.90E-05	3.57E-05
Det. 4	9.61E-07	6.28E-06	7.25E-06
Det. 5	2.35E-07	2.86E-06	3.09E-06
Det. 6	3.96E-07	3.12E-06	3.52E-06
Det. 7	3.02E-06	5.07E-06	8.09E-06
Det. 8	2.12E-06	3.63E-06	5.76E-06
Det. Ref	9.10E-07	3.57E-06	**4.48E-06**

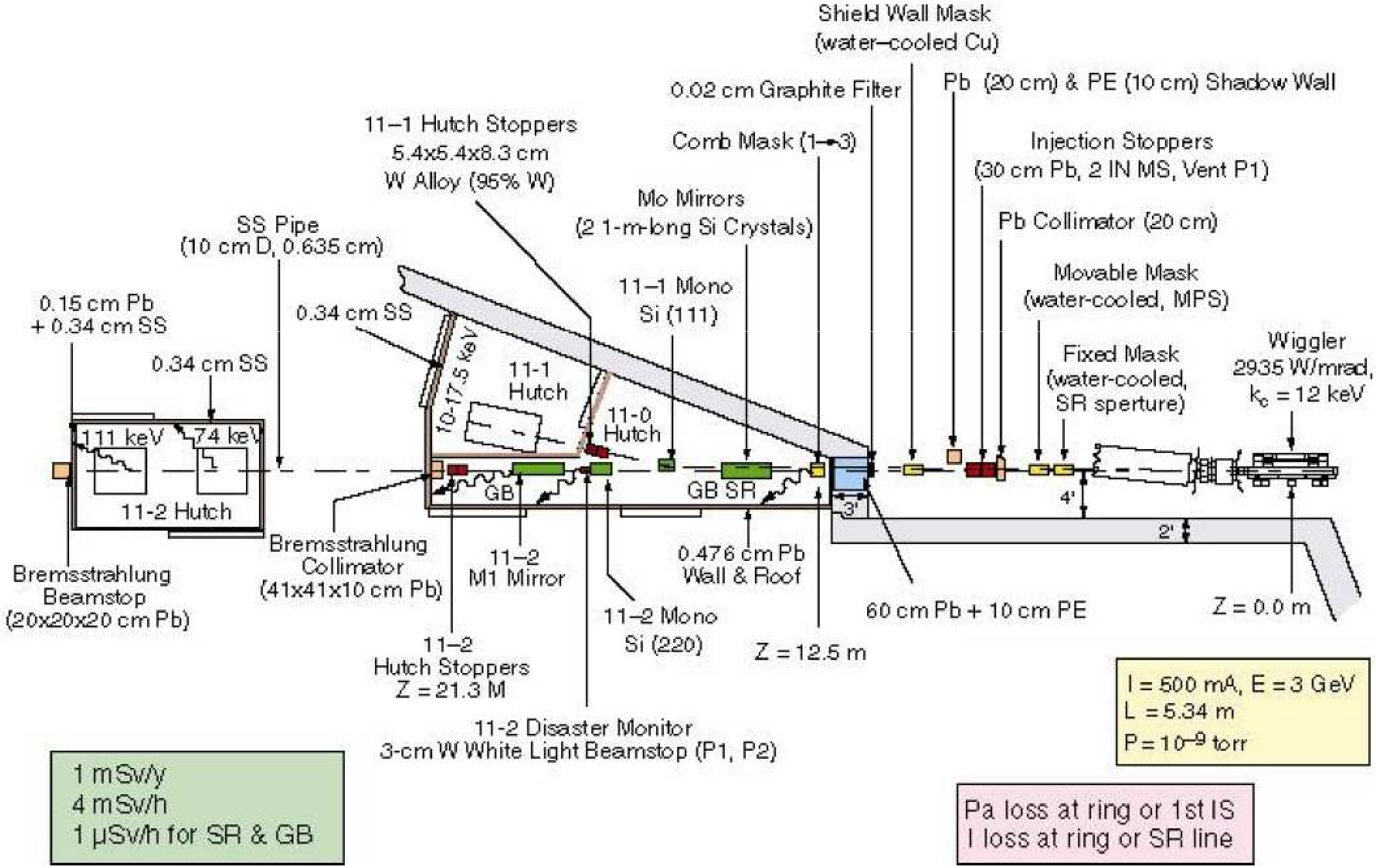
Geometry



Results Comparison

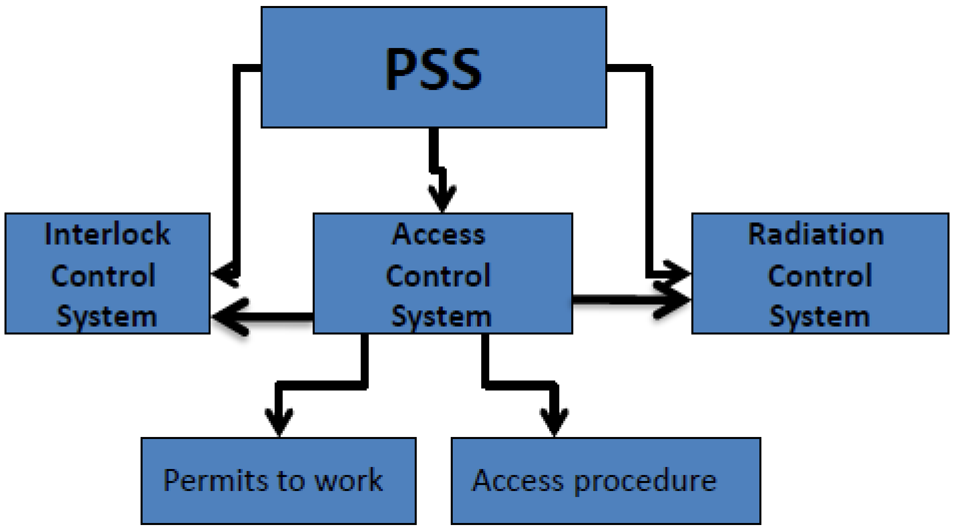
Location	**Total** (pSv/e)	Total (pSv/e) new design
Det. 1	8.67E-03	8.7E-03
Det. 2	1.25E-03	1.25E-03
Det. 3	3.57E-05	2.4 E-05
Det. 4	7.25E-06	5.9 E-06
Det. 5	3.09E-06	1.9 E-06
Det. 6	3.52E-06	2.6 E-06
Det. 7	8.09E-06	4.2 E-0-6
Det. 8	5.76E-06	3.8 E-06
Det. Ref	4.48E-06	4.48E-06

Shielding considerations for a typical synchrotron radiation beamline



Personal Safety System

- PSS restricts and controls the access to forbidden areas i.e. prevents personnel from being exposed while accelerators or/and beam lines are in operation.
- 1-Radiation Control System: keeps radiation away from people
- 2-Access Control System: keep people away from radiation
- 3-Interlock Control System: keep both away from each others



IEC 61508

International Electrotechnical Commission

It rules the use of electrical and software safety systems to provide risk reduction up to an acceptable level

Safety Integrity Level

SIL1 SIL2 SIL3 SIL4

Based on the experience of similar installation, the safety integrity level requires is SIL 3

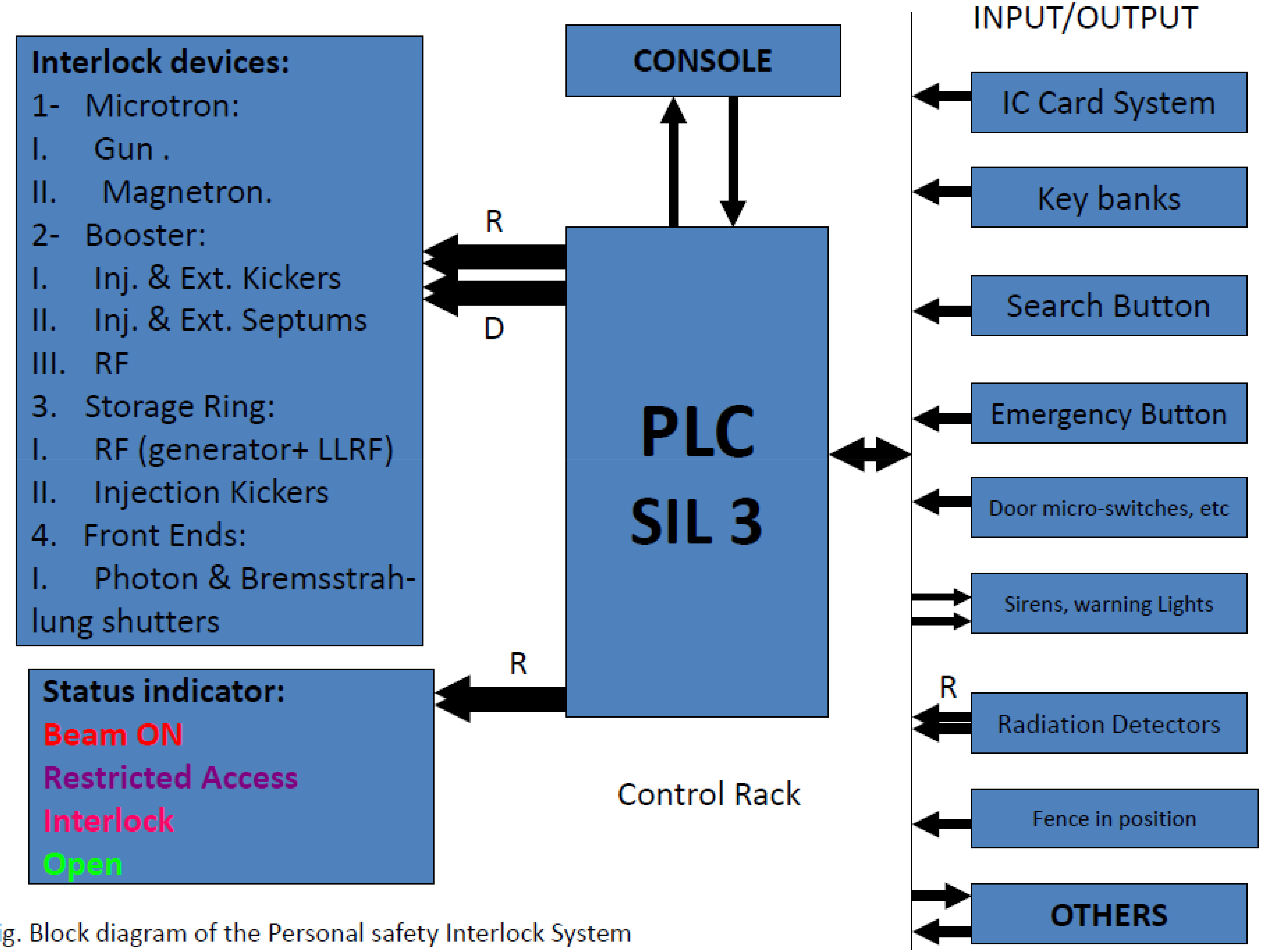
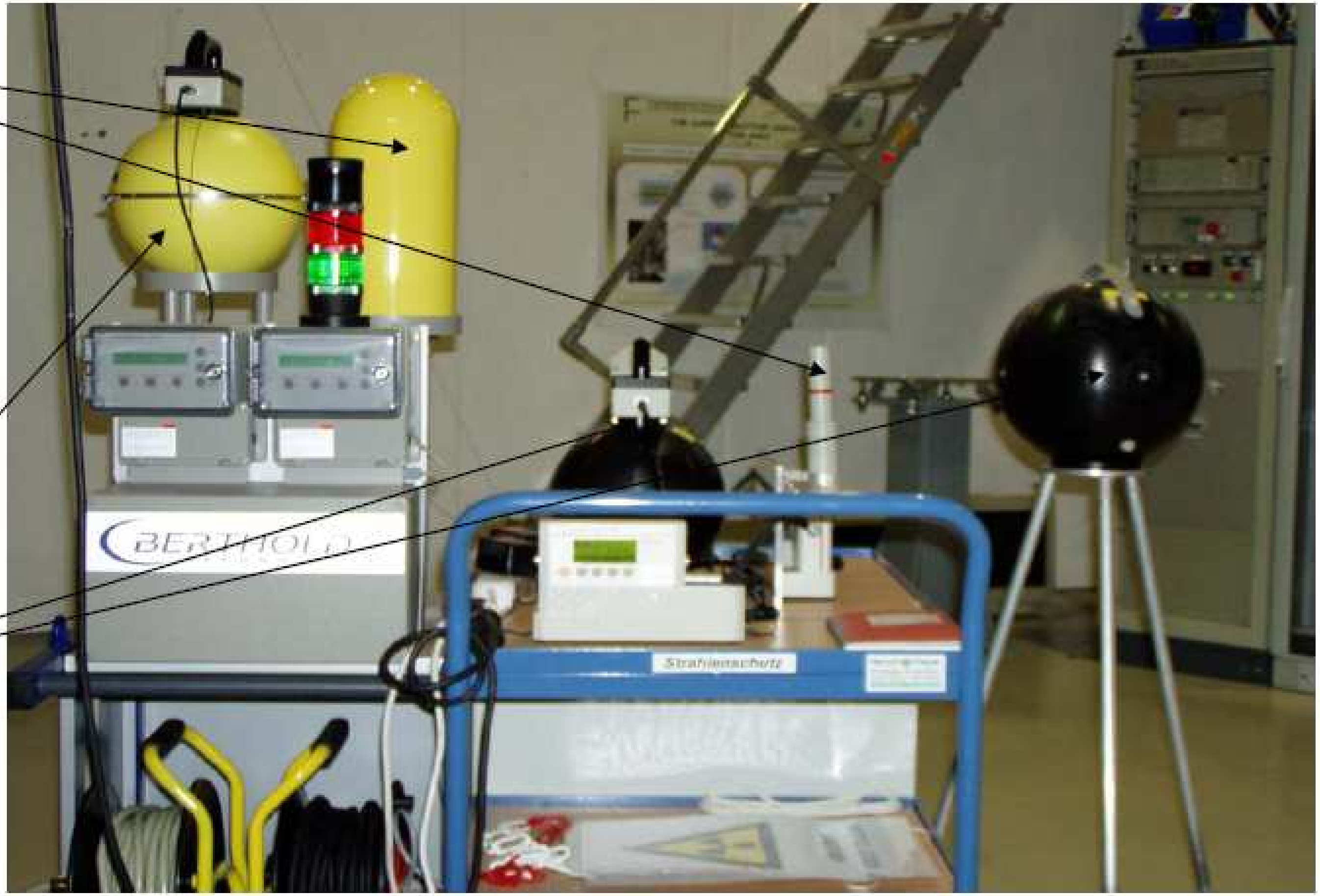


Fig. Block diagram of the Personal safety Interlock System

Radiation Monitoring Devices

Gamma Detectors



Neutron Detectors


Thank you
for
your attention