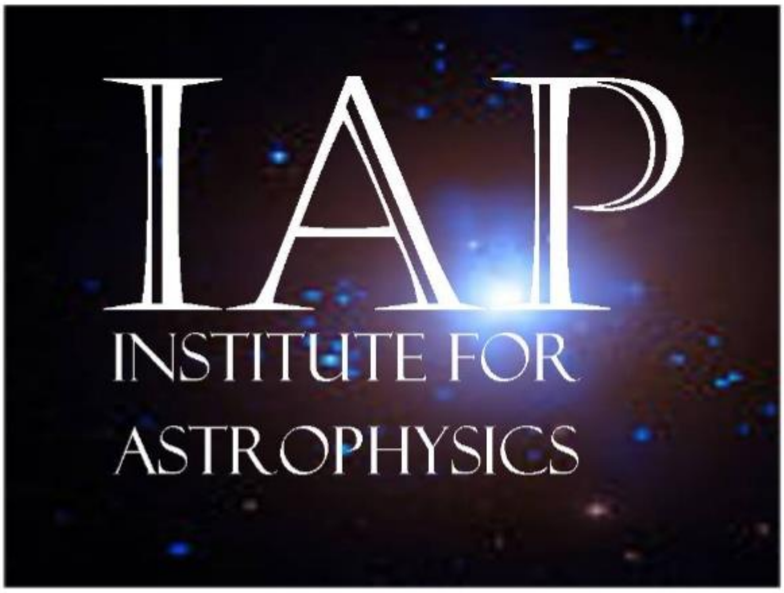
X-Ray and Gamma ray shielding



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Preface

In order to create a workplace isolated of the gamma radius ,we elaborated this document .

1 Introduction

1.1 Gamma ray

1.1.1 Description of Gamma rays

A gamma ray, or gamma radiation (symbol γ), is a penetrating form of electromagnetic radiation arising from the radioactive decay of atomic nuclei. It consists of the shortest wavelength electromagnetic waves and so imparts the highest photon energy.

A gamma ray refers to the high-frequency electromagnetic radiation of a photon whose wavelength is less than about ten nanometers (<10 −8 m), which corresponds to frequencies above about 30 petahertz (> 3 × 10 16 Hz).

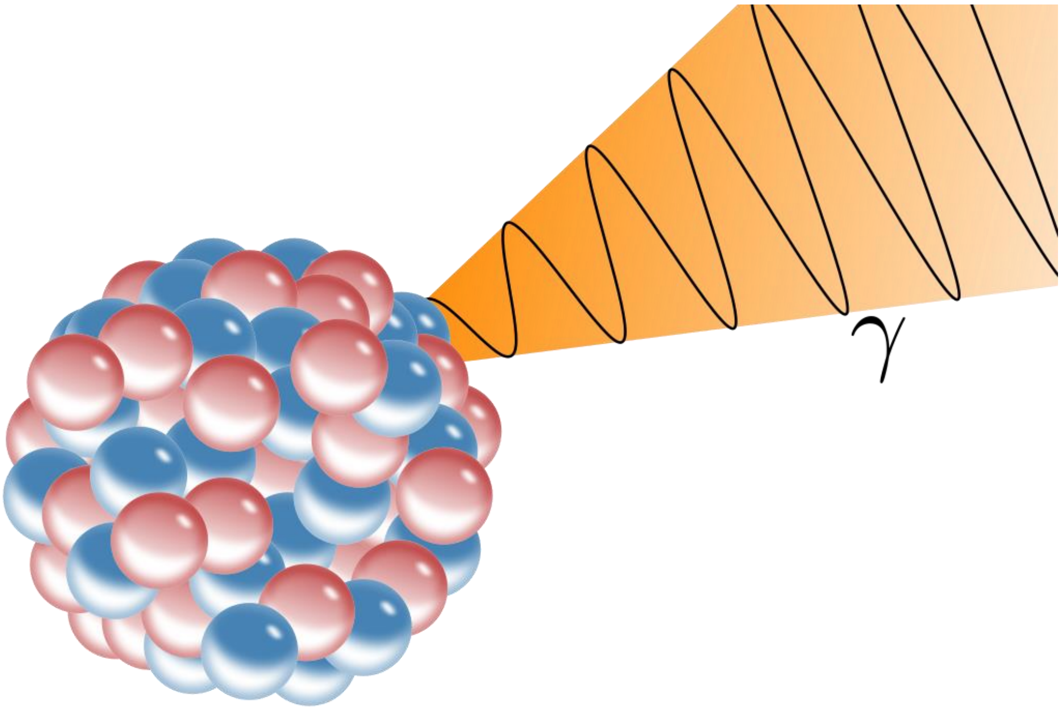


Figure 1: *Illustration of an emission of a gamma ray (γ) from an atomic nucleus*

Gamma rays from radioactive decay are in the energy range from a few kiloelectronvolts (keV) to approximately 8 megaelectronvolts (~8 MeV), corresponding to the typical energy levels in nuclei with reasonably long lifetimes. The energy spectrum of gamma rays can be used to identify the decaying radionuclides using gamma spectroscopy. Very-high-energy gamma rays in the 100–1000 teraelectronvolt (TeV) range have been observed from sources such as the Cygnus X-3 microquasar.

1.1.2 Characteristics of Gamma Rays / Radiation

Key features of gamma rays are summarized in following few points:

✓ Gamma rays are high-energy photons (about 10 000 times as much energy as the visible photons), the same photons as the photons forming the visible range of the electromagnetic spectrum – light.

- ✓ Photons (gamma rays and X-rays) can ionize atoms directly (despite they are electrically neutral) through the Photoelectric effect and the Compton effect, but secondary (indirect) ionization is much more significant.
- ✓ Gamma rays ionize matter primarily via indirect ionization.
- ✓ Although a large number of possible interactions are known, there are three key interaction mechanisms with matter.
    - Photoelectric effect
    - Compton scattering
    - Pair production
- ✓ Gamma rays travel at the speed of light and they can travel thousands of meters in air before spending their energy.
- ✓ Since the gamma radiation is very penetrating matter, it must be shielded by very dense materials, such as lead or uranium.
- ✓ The distinction between X-rays and gamma rays is not so simple and has changed in recent decades. According to the currently valid definition, X-rays are emitted by electrons outside the nucleus, while gamma rays are emitted by the nucleus.

Gamma rays frequently accompany the emission of alpha and beta radiation

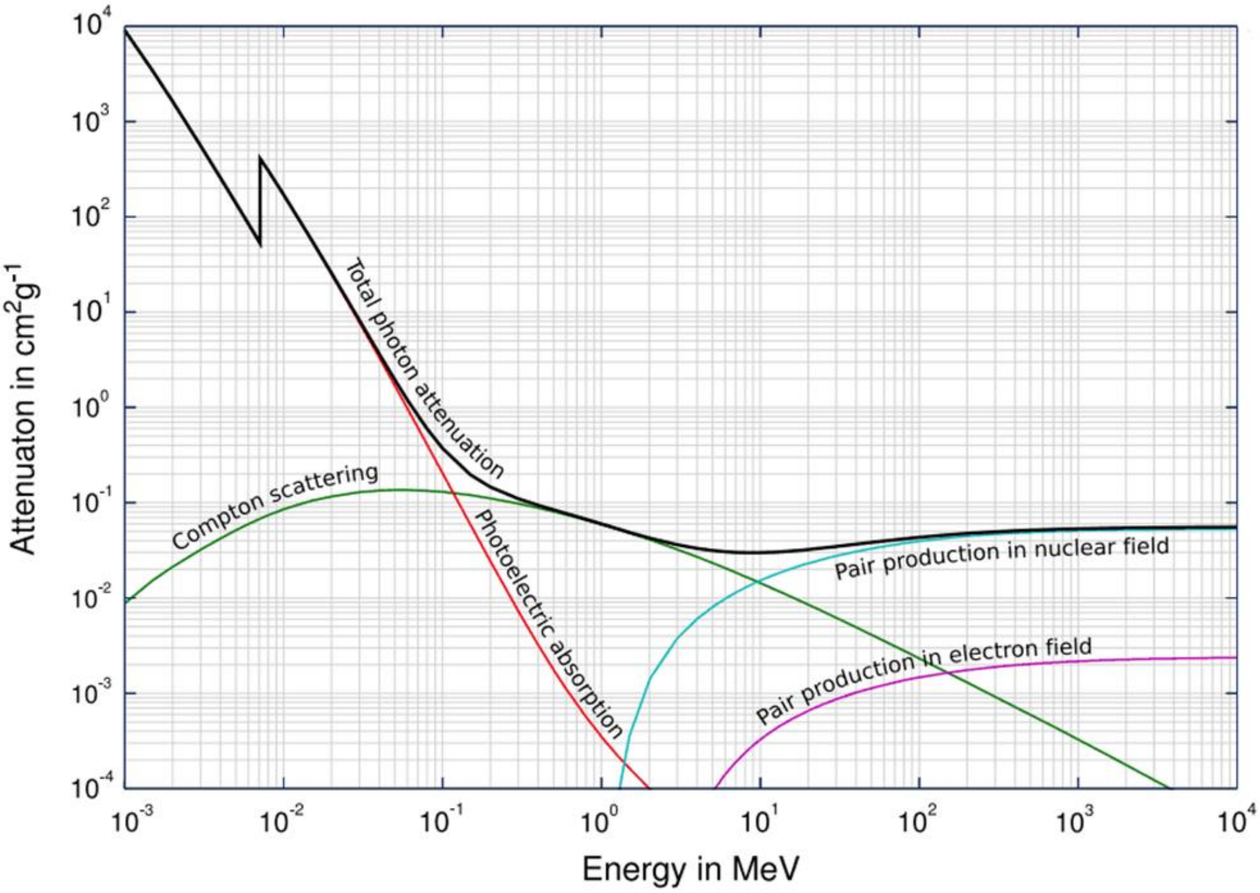


Figure 2: Total photon cross sections.Source: Wikimedia Commons

1.1.3 Sources of Gamma rays

Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes such as potassium-40, and also as a secondary radiation from various atmospheric interactions with cosmic ray(are high-energy protons and atomic nuclei which move through space at nearly the speed of light. They originate from the sun, from outside of the solar system,[1] and from distant galaxies.) particles. Some rare terrestrial natural sources that produce gamma rays that are not of a nuclear origin, are lightning strikes and terrestrial gamma-ray flashes, which produce high energy emissions from natural high-energy voltages. Gamma rays are produced by a number of astronomical processes in which very high-energy electrons are produced. Such electrons produce secondary gamma rays by the mechanisms of bremsstrahlung, inverse Compton scattering and synchrotron radiation. A large fraction of such astronomical gamma rays are screened by Earth's atmosphere. Notable artificial sources of gamma rays include fission, such as occurs in nuclear reactors, as well as high energy physics experiments, such as neutral pion decay and nuclear fusion.

A sample of gamma ray-emitting material that is used for irradiating or imaging is known as a gamma source. It is also called a radioactive source, isotope source, or radiation source, though these more general terms also apply to alpha- and beta-emitting devices. Gamma sources are usually sealed to prevent radioactive contamination, and transported in heavy shielding.

2 Protecting Against Exposure

2.1 Time, Distance and Shielding

There are three general guidelines for controlling exposure to ionizing radiation:

- minimizing exposure time,
- maximizing distance from the radiation source,
- shielding yourself from the radiation source.

Time is an important factor in limiting exposure to the public and to radiological emergency responders. The amount of radiation exposure increases and decreases with the time people spend near the source of radiation. The maximum time to be spent in the radiation environment is defined as the "**stay time.**" The stay time can be calculated using the following equation:

Stay Time = Exposure Limit/Dose Rate

Distance can be used to reduce exposure. The farther away people are from a radiation source, the less their exposure. Doubling the distance from a point source of radiation decreases the exposure rate to 1/4 the original exposure rate. Halving the distance increases the exposure by a factor of four.

How close to a source of radiation can you be without getting a high exposure? It depends on the energy of the radiation and the size (or activity) of the source. Distance is a prime concern when dealing with gamma rays, because they can travel at the speed of light. Alpha particles can only travel a few inches and beta particles around 10 feet.

Shielding: As ionizing radiation passes through matter, the intensity of the radiation is diminished. Shielding is the placement of an "absorber" between you and the radiation source. An absorber is a material that reduces radiation from the radiation source to you. Alpha, beta, or gamma radiation can all be stopped by different thicknesses of absorbers.

Shielding material can **include barrels, boards, vehicles, buildings, gravel, water, lead** or whatever else is immediately available.

stop-alphaα ALPHA – can be stopped after traveling through about 1.2 inches of air, about 0.008 inches of water, or a piece of paper or skin. A thin piece of paper, or even the dead cells in the outer layer of human skin, provides adequate shielding because alpha particles can't penetrate it. However, living tissue inside the body offers no protection against inhaled or ingested alpha emitters.

βstop-beta BETA – can only be stopped after traveling through about 10 feet of air, less than 2 inches of water, or a thin layer of glass or metal. Additional covering, for example heavy clothing, is necessary to protect against beta-emitters. Some beta particles can penetrate and burn the skin.

γ GAMMA: To reduce typical gamma rays by a factor of a billion, thicknesses of stop-gammashield need to be about 13.8 feet of water, about 6.6 feet of concrete, or about 1.3 feet of lead. Thick, dense shielding is necessary to protect against gamma rays. The higher the energy of the gamma ray, the thicker the shield must be. X-rays pose a similar challenge. This is why x-ray technicians often give patients receiving medical or dental X-rays a lead apron to cover other parts of their body.

Source: ANS, The Center for Nuclear Science and Technology Information (http://nuclearconnect.org/know-nuclear/science/protecting#:~:text=Thick%2C%20dense%20shielding%20is%20necessary%20to%20protect%20against,apron%20to%20cover%20other%20parts%20of%20their%20body.)

there are many many materials, which can be used for radiation shielding, but there are many many situations in radiation protection. It highly depends on the type of radiation to be shielded, its energy and many other parametres. For example, even **depleted uranium** can be used as a good protection from gamma radiation, but on the other hand uranium is absolutely inappropriate shielding of neutron radiation.

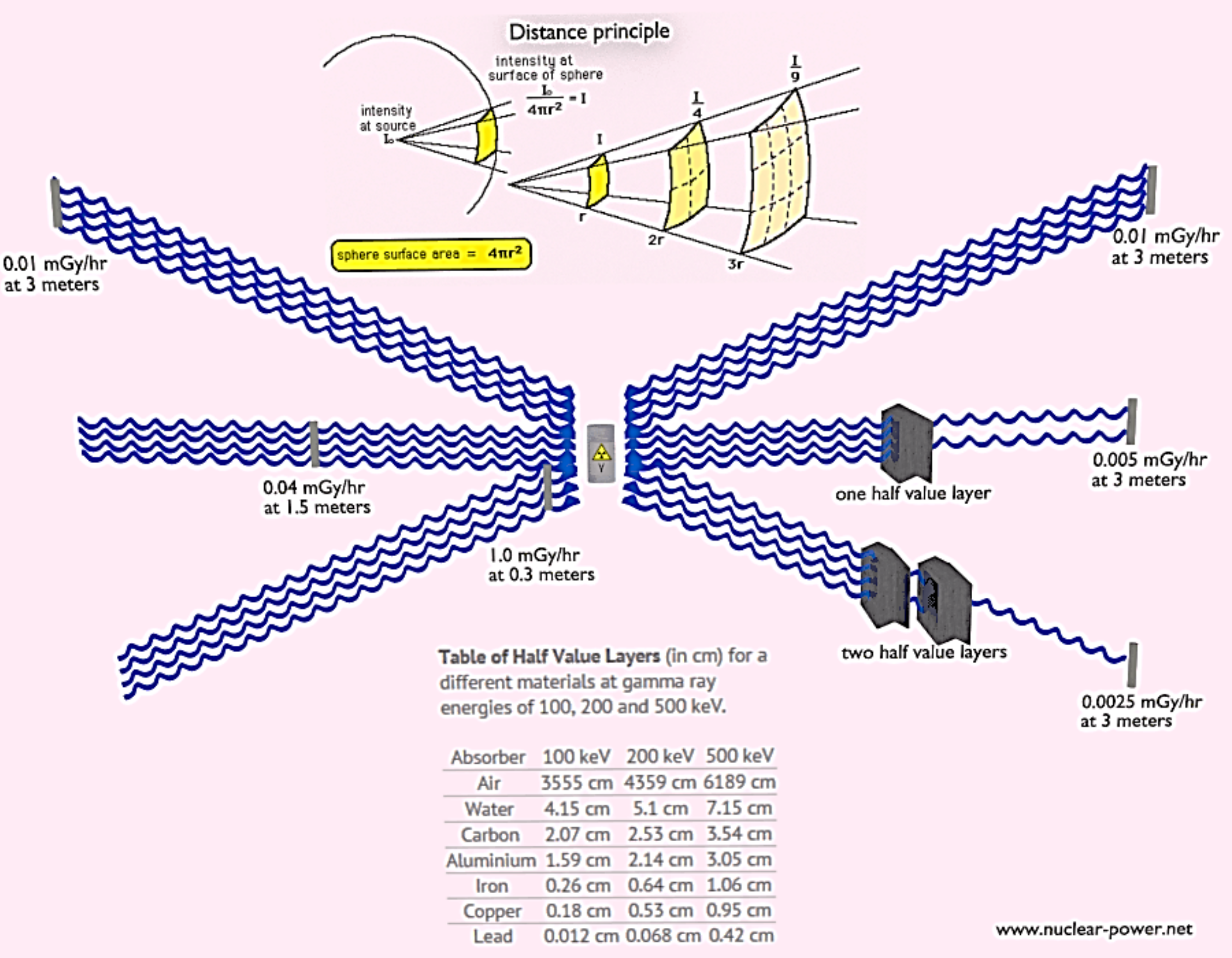


Table of Half Value Layers (in cm) for a different materials at gamma ray energies of 100, 200 and 500 keV.

Absorber	100 keV	200 keV	500 keV
Air	3555 cm	4359 cm	6189 cm
Water	4.15 cm	5.1 cm	7.15 cm
Carbon	2.07 cm	2.53 cm	3.54 cm
Aluminium	1.59 cm	2.14 cm	3.05 cm
Iron	0.26 cm	0.64 cm	1.06 cm
Copper	0.18 cm	0.53 cm	0.95 cm
Lead	0.012 cm	0.068 cm	0.42 cm

Figure 3:Principles of Radiation Protection – Time, Distance, Shielding

2.2 Shielding of Gamma Radiation

In short, effective shielding of gamma radiation is in most cases based on use of materials with two following material properties:

1. high-density of material.
2. high atomic number of material (high Z materials)

However, low-density materials and low Z materials can be compensated with increased thickness, which is as significant as density and atomic number in shielding applications.

A lead is widely used as a gamma shield. Major advantage of lead shield is in its compactness due to its higher density. On the other hand depleted uranium is much more effective due to its higher Z. Depleted uranium is used for shielding in portable gamma ray sources.

In nuclear power plants shielding of a reactor core can be provided by materials of reactor pressure vessel, reactor internals (neutron reflector). Also heavy concrete is usually used to shield both neutrons and gamma radiation.

Although water is neither high density nor high Z material, it is commonly used as gamma shields. Water provides a radiation shielding of fuel assemblies in a spent fuel pool during storage or during transports from and into the reactor core.

In general, the gamma radiation shielding is more complex and difficult than the alpha or beta radiation shielding. In order to understand comprehensively the way how a gamma ray loses its initial energy, how can be attenuated and how can be shielded we must have detailed knowledge of the its interaction mechanisms.

2.3 Gamma Rays Attenuation

The total cross-section of interaction of a gamma rays with an atom is equal to the sum of all three mentioned partial cross-sections:$\sigma = \sigma f + \sigma C + \sigma p$

σf – Photoelectric effect

σC – Compton scattering

σp – Pair production

Depending on the gamma ray energy and the absorber material, one of the three partial cross-sections may become much larger than the other two. **At small values of gamma ray energy** the **photoelectric effect dominates**. **Compton scattering dominates at intermediate energies**. The **compton scattering also increases** with decreasing **atomic number of matter**, therefore the interval of domination is wider for light nuclei. Finally, electron-positron pair production dominates at high energies.

Based on the definition of interaction cross-section, the dependence of gamma rays intensity on thickness of absorber material can be derive. If monoenergetic gamma rays are collimated into a narrow beam and if the detector behind the material only detects the gamma rays that passed through that material without any kind of interaction with this material, then the dependence should be simple exponential attenuation of gamma rays. Each of these interactions removes the photon from the beam either by absorbtion or by scattering away from the detector direction. Therefore the interactions can be characterized by a fixed probability of occurance per unit path length in the absorber. The sum of these probabilities is called the linear attenuation coefficient:

$\mu = \tau(\text{photoelectric}) + \sigma(\text{Compton}) + \kappa(\text{pair})$

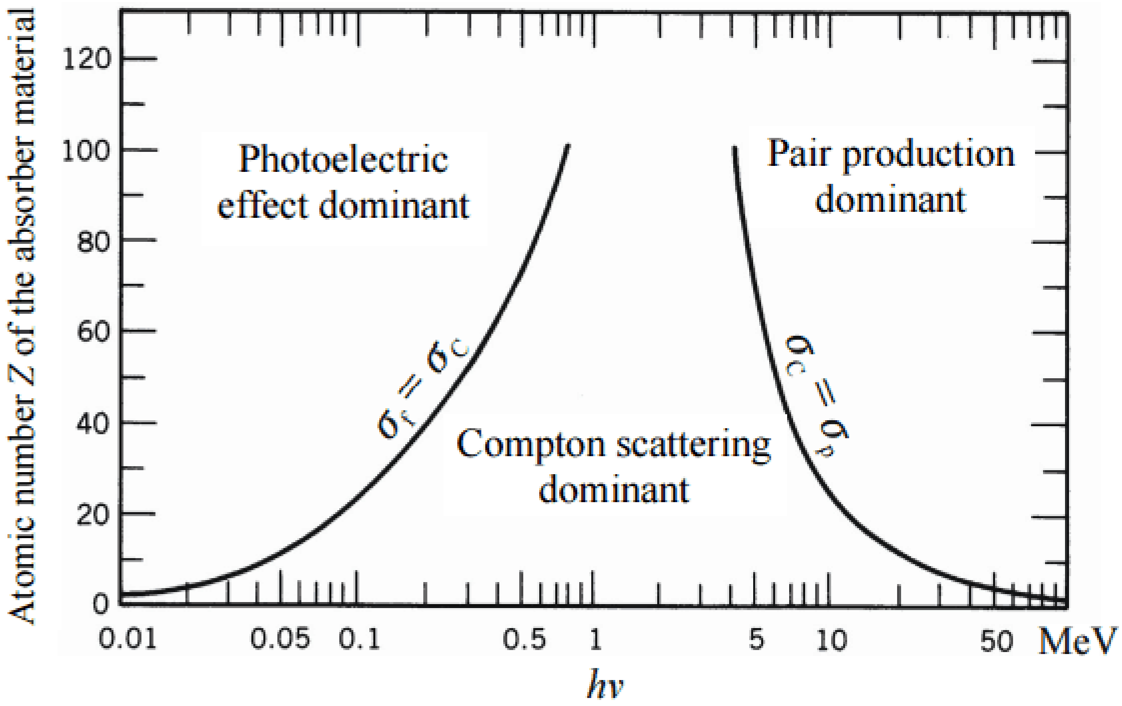


Figure 4: The relative importance of various processes of gamma radiation interaction with matter

2.3.1 Linear Attenuation Coefficient

The attenuation of gamma radiation can be then described by the following equation.

$\boxed{I=I0.e\text{-}\mu x}$, where I is intensity after attenuation, Io is incident intensity, μ is the linear attenuation coefficient (cm^{-1}), and physical thickness of absorber (cm).

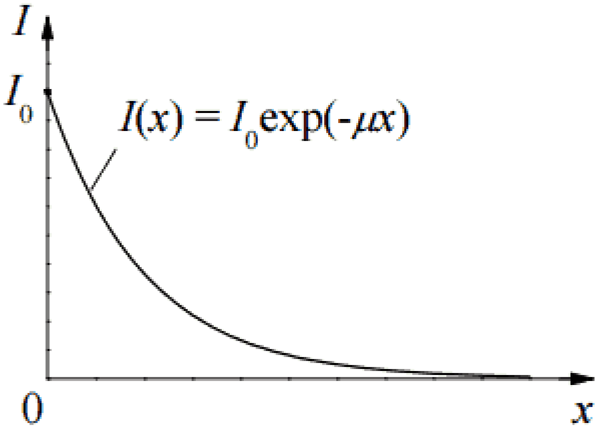


Figure 5: Dependence of gamma radiation intensity on absorber thickness

The materials listed in the table beside are air, water and a different elements from carbon (Z=6) through to lead (Z=82) and their linear attenuation coefficients are given for three gamma ray energies. There are two main features of the linear attenuation coefficient:

- The linear attenuation coefficient increases as the atomic number of the absorber increases.
- The linear attenuation coefficient for all materials decreases with the energy of the gamma rays.

2.3.1.1 Half Value Layer

The half value layer expresses the thickness of absorbing material needed for reduction of the incident radiation intensity by a factor of two. There are two main features of the half value layer:

- The half value layer decreases as the atomic number of the absorber increases. For example 35 m of air is needed to reduce the intensity of a 100 keV gamma ray beam by a factor of two whereas just 0.12 mm of lead can do the same thing.
- The half value layer for all materials increases with the energy of the gamma rays. For example from 0.26 cm for iron at 100 keV to about 1.06 cm at 500 keV.

Example:

How much water schielding do you require, if you want to reduce the intensity of a 500 keV monoenergetic gamma ray beam (narrow beam) to 1% of its incident intensity?

The half value layer for 500 keV gamma rays in water is 7.15 cm and the linear attenuation coefficient for 500 keV gamma rays in water is $0.09 cm^{-1}$.The question is quite simple and can be described by following equation: $I(x) = \frac{I_0}{100}, \; when \; x = ?$

If the half value layer for water is 7.15 cm, the linear attenuation coefficient is:

$$\mu = \frac{ln2}{7.15} = 0.097 cm^{-1}$$

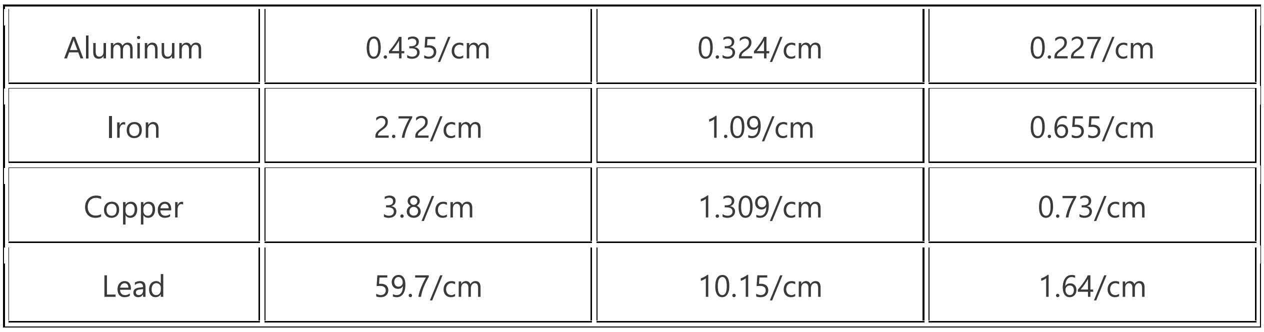
Now we can use the exponential attenuation equation:

$$
\begin{aligned}
I(x) &= I_0 \, exp\,(-\mu x) \\
\frac{I_0}{100} &= I_0 \, exp\,(-0.097x) \\
\frac{1}{100} &= exp\,(-0.097x) \\
ln\frac{1}{100} &= -ln\,100 = -0.097x \\
x &= \frac{ln100}{0.097} = 47.47\ cm
\end{aligned}
$$

The required thickness of water is about 47.5 cm. This is relatively large thickness and it is caused by small atomic numbers of hydrogen and oxygen. If we calculate the same problem for lead (Pb), we obtain the thickness x=2.8cm.

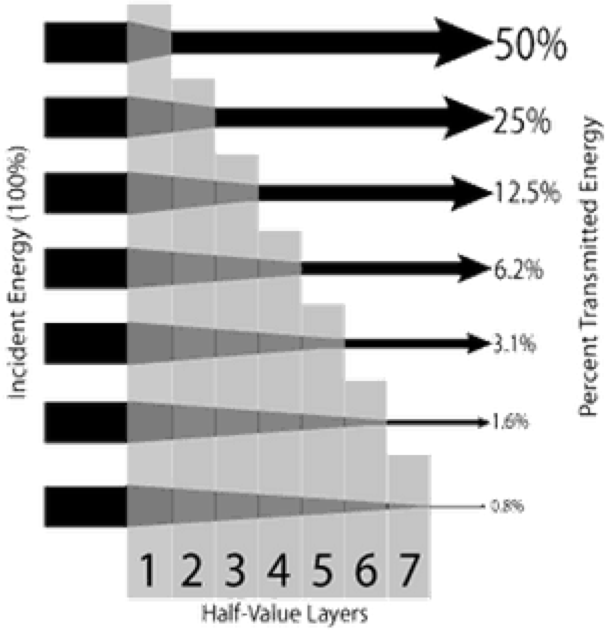
Table of Linear Attenuation Coefficients (in cm^{-1}) for a different materials at gamma ray energies of 100, 200 and 500 keV.

Absorber	100 keV	200 keV	500 keV
Air	0.000195/cm	0.000159/cm	0.000112/cm
Water	0.167/cm	0.136/cm	0.097/cm
Carbon	0.335/cm	0.274/cm	0.196/cm



Aluminum	0.435/cm	0.324/cm	0.227/cm
Iron	2.72/cm	1.09/cm	0.655/cm
Copper	3.8/cm	1.309/cm	0.73/cm
Lead	59.7/cm	10.15/cm	1.64/cm

Half Value Layers



The half value layer expresses the thickness of absorbing material needed for reduction of the incident radiation intensity by a factor of two. With half value layer it is easy to perform simple calculations.

Source: www.nde-ed.org

Table of Half Value Layers (in cm) for a different materials at gamma ray energies of 100, 200 and 500 keV.

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Lead	0.012 cm	0.068 cm	0.42 cm

2.3.1.2 Mass Attenuation Coefficient

When characterizing an absorbing material, we can use sometimes the mass attenuation coefficient. The mass attenuation coefficient is defined as the ratio of the linear attenuation coefficient and absorber density (μ/p). The attenuation of gamma radiation can be then described by the following equation:

$I=I0.e-(\mu/p).pl$

, where p is the material density, (μ/p) is the mass attenuation coefficient and ϱ.l is the mass thickness. The measurement unit used for the mass attenuation coefficient cm2g-1.

For intermediate energies the Compton scattering dominates and different absorbers have approximately equal mass attenuation coefficients. This is due to the fact that cross section of Compton scattering is proportional to the Z (atomic number) and therefore the coefficient is proportional to the material density p. At small values of gamma ray energy or at high values of gamma ray energy, where the coefficient is proportional to higher powers of the atomic number Z (for photoelectric effect σf ~ Z5; for pair production σp ~ Z2), the attenuation coefficient μ is not a constant.

2.3.2 Validity of Exponential Law

The exponential law will always describe the attenuation of the primary radiation by matter. If secondary particles are produced or if the primary radiation changes its energy or direction, then the effective attenuation will be much less. The radiation will penetrate more deeply into matter than is predicted by the exponential law alone. The process must be taken into account when evaluating the effect of radiation shielding.

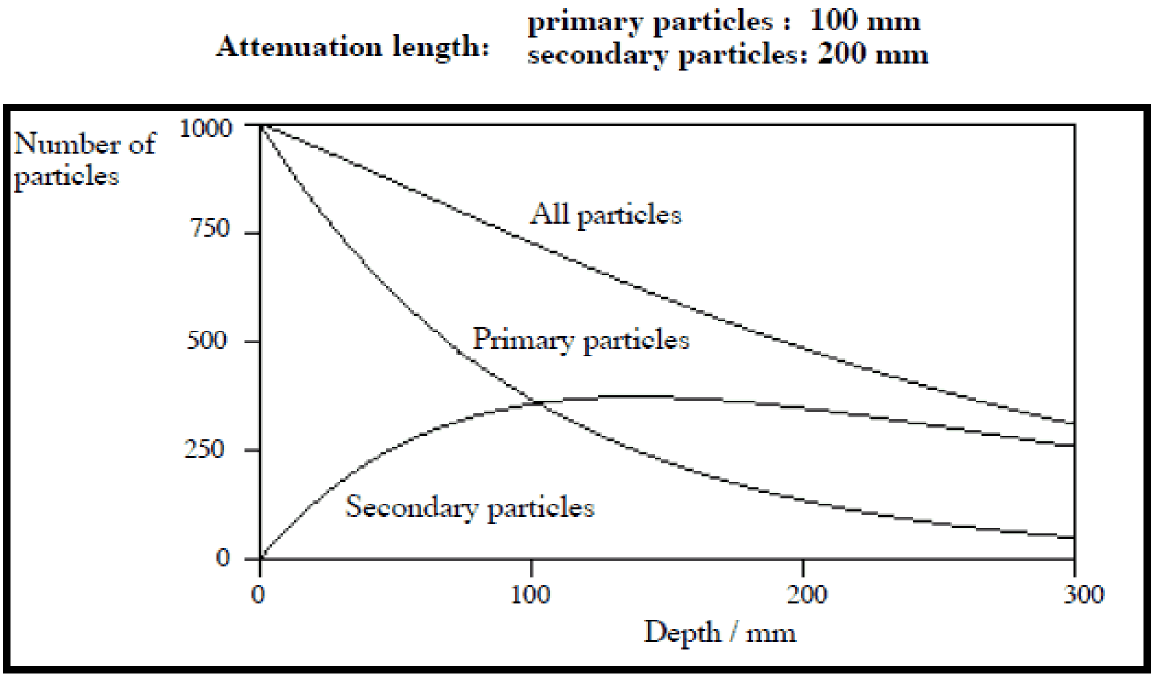


Figure 6: Example of build-up of secondary particles. Strongly depends on character and parameters of primary particles

2.3.3 Buildup Factors for Gamma Rays Shielding

The buildup factor is a correction factor that considers the influence of the scattered radiation plus any secondary particles in the medium during shielding calculations. If we want to account for the buildup of secondary radiation, then we have to include the buildup factor. The buildup factor is then a multiplicative factor which accounts for the response to the uncollided photons so as to include the contribution of the scattered photons. Thus, the buildup factor can be obtained as a ratio of the total dose to the response for uncollided dose.

The extended formula for the dose rate calculation is:

$$\dot{D} = \frac{kSE\frac{\mu_t}{\rho}Be^{-\mu D}}{4\pi r^2}$$

where

- k is a collective constant to convert energy fluence rate to dose rate; for gray/hour, k will have a value of 5.76×10^{-7}
- S is the source strength in s^{-1}
- E is the photon energy in MeV
- $\frac{\mu_t}{\rho}$ is the mass absorption coefficient for the material at the dose (values are available at NIST)
- B is the buildup factor (tabulated), which depends on the photon energy, the shield material and thickness, the source and shield geometry, and the distance from the shield surface to the dose point.
- μ is the linear attenuation coefficient for the photons in the shield material (values are available at NIST)
- D is the thickness of the shield

3 Pulsed power accelerators

Pulsed power accelerators have been used for many years as intense sources of X-rays.

The dominant trend in the development of pulsed power accelerator technology over the last decade has been towards higher power and shorter pulse widths.

Limitations in high voltage,high current switch performance,and in power fiow through vacuum insulator housings led to the development of highly modular designs. This modular approach requires precise synchronization of the various modules and efficient methods of combining the power from these modules to drive a common load.

3.1 Construction and operation

The machines which have been constructed consist of three or more essential elements, an energy-storage device such as a Marx generator, a pulse-forming network, and a diode used for beam generation. the pulse line provides a fast-rise, short-duration pulse which is applied to the vacuum diode.

The pulsed electron accelerator consists from electron source with vacuum chamber for irradiation, Marx high voltage pulsed generator .Planar diode electron source has explosive emission cathode on the basis of carbon fiber materials and carbon nanotubes . The diameter of cathode is 1.0 – 10.0 cm. An anode is metal net from stainless steel. The pressure of residual gas in stainless steal vacuum chambers is 10-5 Torr. The nylon high voltage insulator has evacuated central metal electrode for connection with cathode. The Ti foil with thickness 15 microns uses for output electron beam from vacuum chamber to air. The two separated Marx generators with pulse duration 20 and 100-200 nsec are used in this accelerator in dependence on pulse duration. The regulation of output voltage from Marx generator realizes by variation of charging voltage and gas pressure in the sparks.

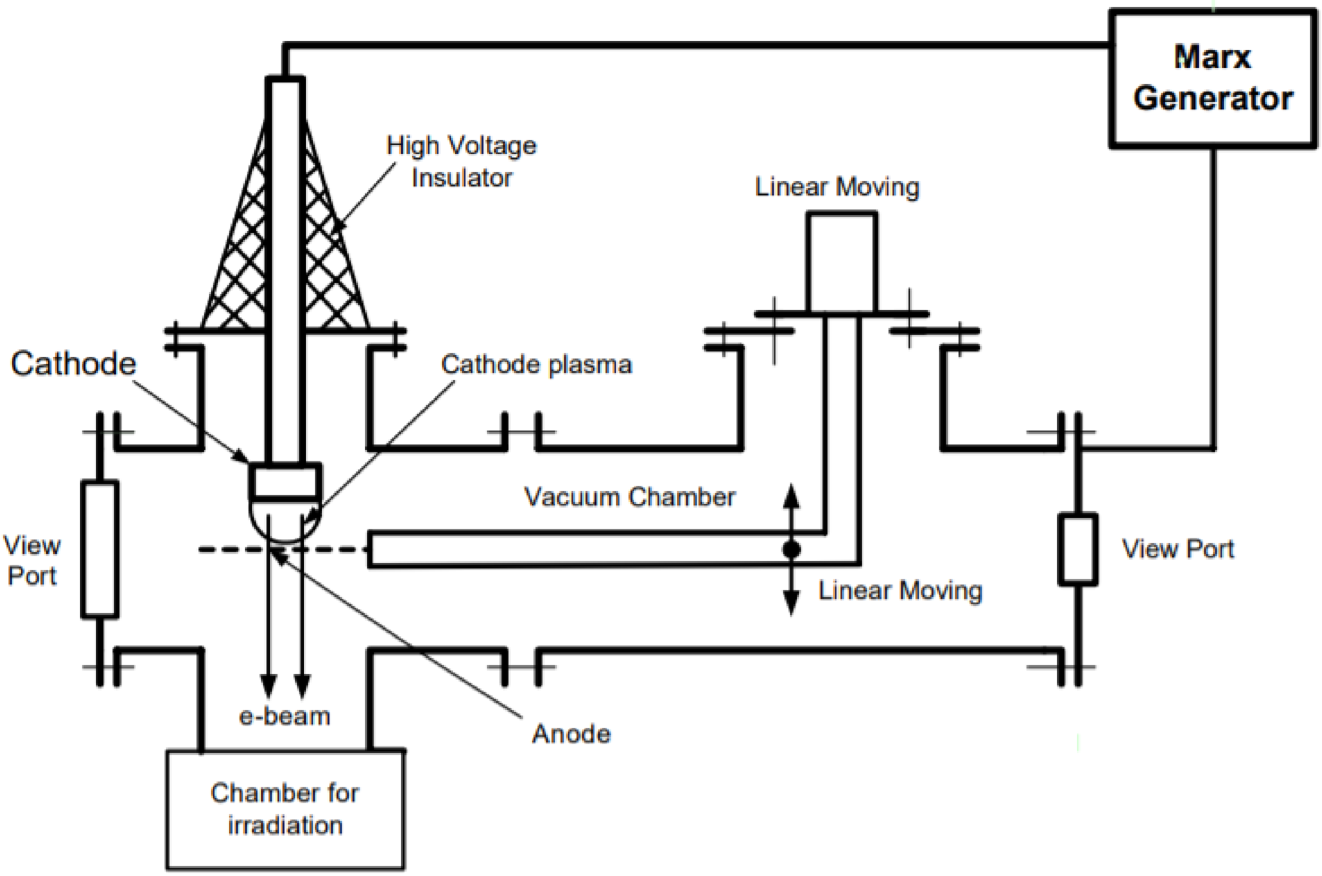


Figure 7: The structure of electron accelerator.

3.2 MAIN PARAMETERS OF ACCELERATOR

The main parameters of electron accelerator are next: 1. Kinetic energy………………..200 – 400 keV. 2. Beam current…..………………...10 – 1000 A. 3. Beam pulse duration ………..20 and 100 nsec. 4. Repetition…..………………0.01 - 10 Hz. The change of pulse duration 20 and 100 nsec is realized by change of type for Marx generator.

4 Monitoring Radiation Exposure

Personal radiation detection devices (Luxel Aluminum Oxide or Thermo-Luminescence Dosimeters - TLD badges) are used to monitor the radiation dose that a wearer may have received from an exposure, but these devices offer no additional protection to the wearer. These devices measure exposure in only a small area of the body. The chances of these devices being located in an area of the body that is exposed is very small.

4.1 Measurement of beam current

The beam diagnostic includes the standard units. The current transformers (Rogowski Coils) and Faraday Cups are used for measurements of beam current. The high resistive dividers are used for measurements of accelerating voltage. The block-diagram of system for beam measurement is given on next Fig. This system uses PXI-1025, scope, switches and software LabVIEW 6.1. from National Instruments.

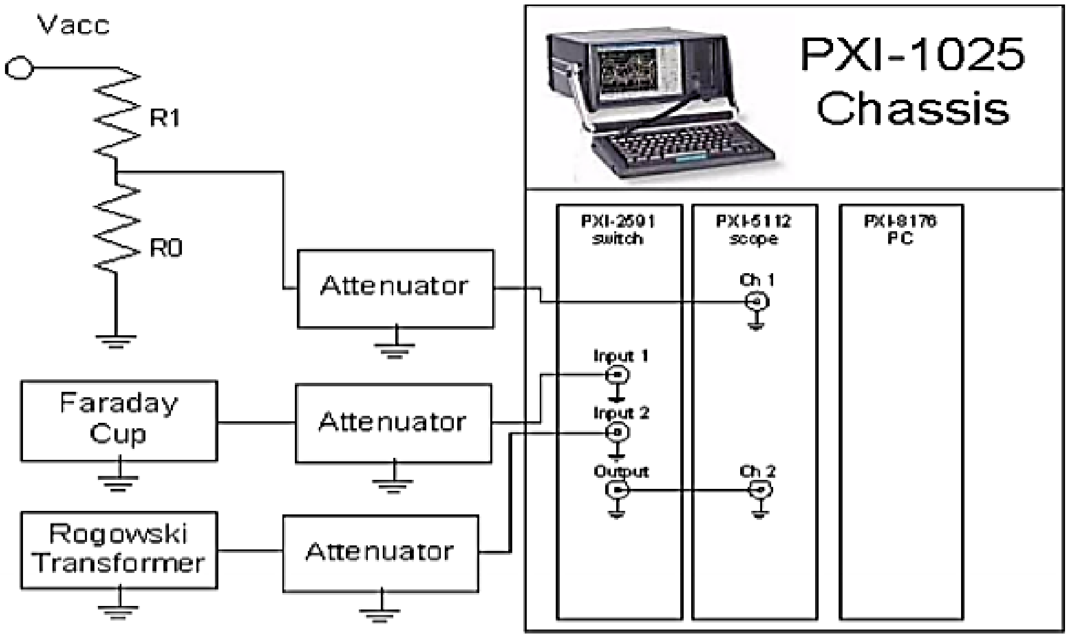
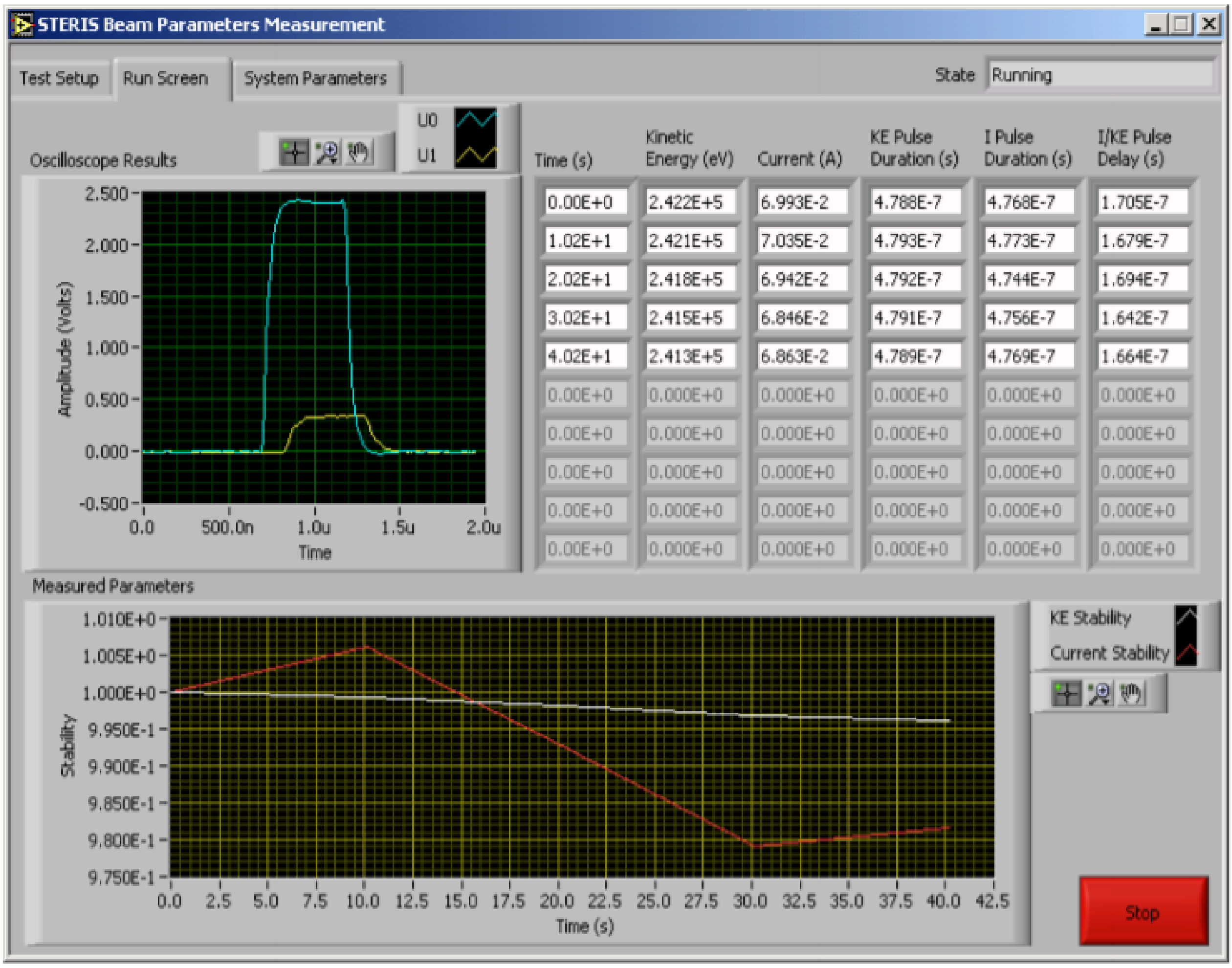


Figure 8:the diagram of beam parameters measurement system.



State: Running

Time (s)	Kinetic Energy (eV)	Current (A)	KE Pulse Duration (s)	I Pulse Duration (s)	I/KE Pulse Delay (s)
0.00E+0	2.422E+5	6.993E-2	4.788E-7	4.768E-7	1.705E-7
1.02E+1	2.421E+5	7.035E-2	4.793E-7	4.773E-7	1.679E-7
2.02E+1	2.418E+5	6.942E-2	4.792E-7	4.744E-7	1.694E-7
3.02E+1	2.415E+5	6.846E-2	4.791E-7	4.756E-7	1.642E-7
4.02E+1	2.413E+5	6.863E-2	4.789E-7	4.769E-7	1.664E-7
0.00E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0
0.00E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0
0.00E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0
0.00E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0
0.00E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0	0.000E+0

Figure 9:The monitoring screen for beam parameters measurement system

5 DESIGN OF X-RAY ROOMS

5.1 Room size

General radiographic rooms should be approximately $16m^2$. There should be sufficient space for a permanently built protective cubicle.

5.2 Doors and Walls

- Access doors should be of the sliding type giving better radiation protection.
- A clearing of 1.5 m is recommended. The overlap should be 100 mm each side.
- The doors should be lined with leadsheet of 2 mm thickness.
- The walls should be 230 mm kiln baked solid clay brick or 2 mm leadsheet sandwiched between partitioning or 115 mm brick with 6 mm barium plaster.
- Walls should be protected up to a height of 2.2 meter.

5.2.1 Lead equivalence

Material	Thickness of material (in mm)	Lead equivalence (in mm) at tube voltage	
		100 kV	**150 kV**
brick	115	1.0	0.9
brick	230	2.4	2.0
barium plaster	6	1.0	0.55
barium plaster	11		1.0

Barium plaster

Barium plaster mix:

1 part coarse barium sulphate

1 part fine barium sulphate, 1 part cement

5.2.2 Windows and air conditioning units

- Windows and air conditioning units should be sited at least 2 m above the floor. Alternatively access near the window must be prevented effectively.
- Windows of upper floor x-ray rooms can be of normal height.

5.3 Protective cubicle

- A protective cubicle allowing space for the control as well as the operator should be constructed in the x-ray room.
- The cubicle should be located such that unattenuated direct scatter radiation originating on the examination table or the erect bucky do not reach the operator in the cubicle.
- The x-ray control for the system should be fixed within the cubicle and should be at least 1.02 m from any open edge of the cubicle wall which is nearest to the examination table.
- The size of the window should be at least 30 cm x 30 cm.
- The minimum height of the cubicle is 2.2 meter.
- The lead equivalence of the wall or panel as well as the protective glass should be at 2 mm, i.e., 230 mm brick or 115 mm brick barium plastered (6 mm) or 2 mm leadsheet.