SHIELDING USE AND ANALYSIS

PURPOSE

This handout discusses the principles of shielding use and analysis for the four main types of radiation encountered at Hanford facilities.

SHIELDING

Of the three basic principles of external radiation protection (time, distance, and shielding) shielding is generally the preferred method because it results in intrinsically safe working conditions, whereas reliance on distance and time of exposure, involve continuous administrative control over workers. Source reduction is an important method of reducing dose too, but this handout concerns the effective use of shielding to attenuate radiation.

The amount of shielding required depends on the type of radiation being shielded, the activity of the source, and on the dose rate which is acceptable outside of the shielding material. In choosing a shielding material, the first consideration must be personnel protection. An effective shield will cause a large energy loss in a small penetration distance without emission of more hazardous radiation. However, other factors may also influence the choice of shielding materials such as, cost of the material, weight of the material, and how much space is available for the material. The effectiveness of the shielding material is determined by the interactions between the incident radiation and the atoms of the absorbing medium. The interactions which take place depend mainly upon the type of radiation (alpha, beta, gamma, and neutron), the energy of the radiation, and the atomic number of the absorbing medium.

ALPHA RADIATION

Alpha particles lose energy rapidly in any medium because of their relatively high ionization loss and are stopped by very thin absorbing materials. A few sheets of paper or thin aluminum foil will absorb alpha particles from alpha-emitting sources. The most energetic alpha will travel only a few tens of mm in air. The outer layer of skin, approximately 0.07 kg/m2 in thickness, will absorb alpha particles up to 7.5 MeV. Since this is a dead layer of tissue, no harmful effect is produced upon the body. Therefore alpha particles do not present a shielding problem.

BETA RADIATION

Beta particles have a very small mass and one-half the magnitude of the charge of alpha particles. So for a given energy, beta particles have a much greater velocity than alpha particles. As a result beta particles have a lower specific energy loss, which means that their penetration in any absorber will be much greater than that of alpha particles.

The process by which beta particles lose energy in absorbers are similar to those for alpha particles. However, an additional problem encountered when shielding against beta radiation is the process whereby electromagnetic radiation (secondary X-rays), called bremsstrahlung, are produced. The fraction of beta energy reappearing as bremsstrahlung is approximately $ZE/3000$ where Z is the atomic number of the absorber and E is the beta energy in MeV. This means that shielding for beta radiation should be constructed of materials of low-atomic-number to reduce the amount of bremsstrahlung emitted.

A beta source emits beta rays with energies covering the complete spectrum from zero to a characteristic maximum energy, E_{max}. The mean beta energy is, in most cases, about $1/3E_{max}$. The penetrating power of beta particles depends in their energy. For example, a 1 MeV beta particle will travel about 3.5 m in air. Therefore the thickness and choice of material for shielding from beta radiation depends upon: stopping the highest energy beta, for example Sr90 emits a .546 MeV beta while its daughter Y90 emits a 2.27 MeV; and shielding any bremsstrahlung.

The first table below provides thicknesses of low Z materials in inches to absorb beta radiation, and the second table below provides the percentage of 1 MeV Beta particles absorbed by specific materials and equipment.

Thicknesses of low Z materials in inches, to absorb beta radiation

Energy (MeV)	**Plastic (Lucite)**	**Concrete**	**Aluminum**
0.5	0.1	0.05	0.05
1.0	0.2	0.1	0.1
2.0	0.3	0.2	0.2
3.0	0.4	0.3	0.3

Percentage of 1 MeV Beta particles absorbed by materials and equipment

Materials and Equipment	**% Absorbed**
Cotton Coveralls	20
Plastic Hoods or Goggles	30
Cotton or rubber gloves	30
Neoprene gloves	50
Paper (0.3 mm)	90
Safety glasses or respirator	90

GAMMA RADIATION

Gamma rays do not lose energy continuously, as do alpha and beta particles, when passing through an absorber. As a result gamma rays are much more penetrating than alpha or beta particles. Gamma radiation is attenuated exponentially when it passes through a shielding material. Therefore, theoretically, gamma rays are never completely absorbed no matter how thick the shield. Nevertheless, we can choose a shield thickness which reduces the dose rate to an acceptable level.

The dose rate due to gamma radiation emerging from a shield can be written as:

$$D_t = D_o e^{-ìt} \qquad (1)$$

where D_o is the dose rate without shielding, D_t is the dose rate after passing through a shield of thickness t, and ì is the linear absorption coefficient of the shielding material. The linear absorption coefficient ì is a function of the type of material used for the shield and the energy of the gamma radiation. It has dimensions of $(\text{length})^{-1}$.

Equation (1) is useful for calculating the dose rate for a narrow beam source geometry. However, this equation underestimates the required shield thickness for broad beam source geometry or for thick shields because it assumes that every gamma ray that interacts with the shield is removed from the beam, and thus does not contribute to the dose rate.

For a broad beam source geometry or a thick shield the dose rate is a function of the gamma rays that pass through the shield without any interaction and the scattered gamma rays and gamma rays generated through interactions of the incident gamma rays. Therefore the total dose rate can be written as:

$$D_t = D_u + D_s \qquad (2)$$

where D_u is the dose rate from the unscattered gamma rays and D_s is the dose rate from the scattered gamma rays and generated gamma rays. Instead of calculating D_s we usually introduce a term to equation (1) called the dose buildup factor B, such that:

$$D_t = BD_u e^{-ìt} \qquad (3)$$

where D_u is the dose rate without shielding, D_t is the dose rate after passing through a shield of thickness t, ì is the linear absorption coefficient of the shielding material, and B is the dose buildup factor.

The value of B is a function of the energy of the incident gamma rays, shield material, source geometry, and shield thickness. Values for B are usually looked up in tables and not calculated. For example, the Radiological Health Handbook provides a table of dose buildup factors for various gamma ray energies and materials.

For quick shielding estimates the concept of half-value layer is very useful. The Half-Value Layer (HVL) for a particular shielding material is the thickness required to reduce the intensity to one half its incident value. One HVL reduces the intensity to one-half, two HVLs reduces the intensity to one-quarter, three HVLs to one-eighth and so on. To use half-value layers:

$$D_s = D_o\ (?)^n \qquad (4)$$

where D_s is the desired shielded dose rate, D_o is the unshielded dose rate, and n is the number of half-value layers. The following table provides HVLs, in inches of shielding material, for various gamma energies and materials.

HVLs in inches for various energies and materials				
Energy MeV	**Lead**	**Iron**	**Concrete**	**Water**
0.5	0.2	0.4	1.3	3.0
1.0	0.3	0.6	1.8	3.9
1.5	0.5	0.7	2.3	4.8
2.0	0.6	0.8	2.6	5.5

NEUTRON RADIATION

Neutron, like gamma rays, are highly penetrating forms of radiation. Neutrons possess no charge and, therefore, are unaffected by the electric fields of absorber atoms. Neutron attenuation is accomplished mainly through elastic and inelastic scatter, which reduce the energy of the neutron until it is absorbed (neutron capture) in the shielding material.

Elastic scatter is where the neutron collides with the target nucleus and bounces off similar to the collision of two pool balls. During the collision, the neutron loses some of its initial energy and this energy is transferred to the target nucleus. Light elements are best for slowing down neutrons by elastic scatter and so materials with a high hydrogen content, such as water, concrete, and plastic are used. Inelastic scatter is where the incoming neutrons impart some of their energy to the scattering material and excite the target nuclei. The excited target nuclei emits gamma rays as it return to its ground state. Neutron capture is the process where neutrons are captured by the target nuclei which then de-excite by emitting another particle or gamma ray.

Neutrons are most effectively shielded by materials containing low-atomic-number absorbers. Neutrons are slowed to thermal energies by elastic collision and then they are captured by nuclei of the shielding material. Materials commonly used to shield neutrons are concrete, water, and polyethylene.