# Elementary Concepts of Shielding

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## Radiation Transport

Shielding is the use of materials to mitigate the effects of incident radiation, by reducing the intensity of the radiation inside the shielded volume, by changing the deleterious properties ("quality") of the radiation, or both. Examples of reducing the intensity of radiation are: attenuation of x-rays by absorption of photons in a lead curtain; attenuation of neutrons by nuclear interactions in hydrogenous materials; stopping of high-energy heavy ions in lunar regolith. Examples of changing radiation quality are: moderation of neutrons in hydrogenous materials, which changes their energy but not their number; projectile fragmentation in spacecraft shielding, which results in lighter pieces of the incident projectile with less ionization density (LET).

Most shielding materials will change the energy, direction and kind of particles comprising the radiation field. The iron Bragg curves of Fig. E.2 show how the relative dose decreases in a water absorber. This decrease is due to a combination of effects. On the one hand, incident Fe nuclei suffer nuclear interactions. In some of these nuclear interaction, parts of the Fe nuclei are emitted approximately in the same direction and with the same velocity as the incident nucleus. These parts are lighter nuclei with lower charge Z (fewer protons) and they ionize less, proportional to $Z^2$ . In other reactions, nuclei of Fe may fragment entirely and be removed from the stream of particles. On the other hand, the Fe nuclei and the nuclear interaction products that do not interact continue losing energy. The slower particles have greater LET, resulting in higher relative doses. Finally, near the end of their range, the particles stop, and are removed from the radiation field; the heaviest particles with the highest charge lose most energy and are stopped first.

Shielding materials are generally "thick" materials, in the sense that they present enough matter to the incident material so that the energy losses of incident charged particles can be large (to the point of stopping in the material) or multiple nuclear interactions can occur to successive generations of secondary particles. The calculation of the number of particles, and of their kinds, energies and directions inside or behind any material is known as a "radiation transport" calculation. It is the means to predict how the radiation environment external to any human habitat is transformed by the presence of the materials of which the habitat is constructed.

Radiation transport calculations require accurate accounting, at each generation of interactions, of each particle's change of identity, energy, and direction. In the case of neutrons, where the number of particles is small, and the different kinds of particles are limited, Monte Carlo methods have been used to make such calculations. In a Monte Carlo calculation, random numbers are generated for the particle position, energy and direction and the probablity of a nuclear interaction is computed, yielding a set of numbers describing the particle's new energy, position, and direction. This particle is followed until it is removed from the radiation field, and a similar computation is started for the next particle. If very large numbers of particles need to be simulated, Monte Carlo calculations can take a very long time and be very costly.

For modeling the transport of nucleons (neutrons and protons) through arbitrary target materials, a deterministic nucleon (BaRYoN) TRaNsport code, named BRYNTRN, has been developed by NASA at the Langley Research Center. The current version of the code accepts continuous spectral distributions from SPE / GCR protons as input. For modeling the transport of GCR (nucleons and HZE particles) and their reaction products through arbitrary target materials, NASA uses a deterministic HZE TRaNsport code, named HZETRN. Computer codes for the propagation of GCR also exist in Russia and Europe.

## Shield Material Characteristics

Desirable shielding materials will result in high energy loss (stopping power) by the incident particle, while at the same time resulting in a low probability of nuclear interactions that might lead to projectile fragments. Since energy loss depends on the number of electrons, while nuclear interactions depend on the number of nucleons, the best shielding materials are likely to be those that have the highest ratio of electrons to protons. Hydrogen, with exactly one electron and a one-proton nucleus, has an electron/proton ratio of 1, higher than that for any other element, and is thus the most desirable component to use in shielding materials. Wilson and his colleagues at LaRC have done extensive analyses of hydrogen-containing materials. A discussion of their

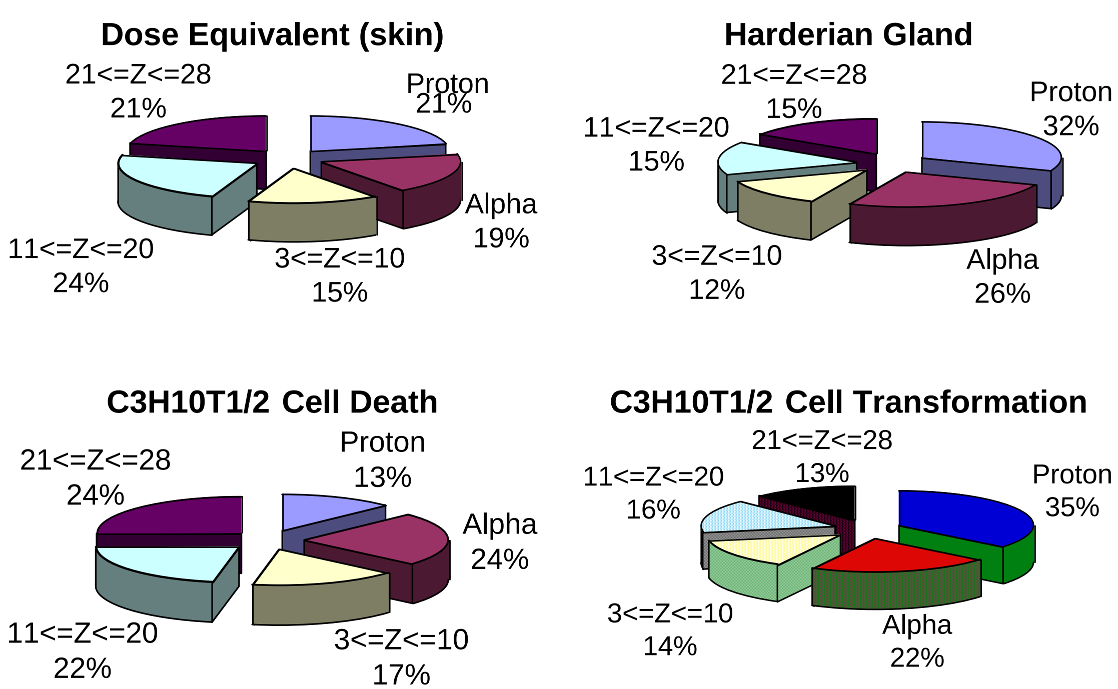


**Figure G. 1. Primaries and Secondaries Inside 5 g/cm$^2$ of Aluminum**

structural and other properties, and of the issues involved in shielding optimization can be found in the workshop report “Shielding Strategies for Human Space Exploration.”

The results of a conventional radiation transport calculation specify the physical characteristics of the radiation field inside or behind shielding. However, in order to estimate risk, it is necessary to calculate the dose, dose equivalent, or other properties of the radiation field. As illustrated in Fig. G.1, the contribution of the various particle species inside 5 $g/cm^2$ of Al shielding is different for different biological endpoints, illustrating the requirement to characterize shielding efficacy in biological terms. As shown by Wilson and his colleagues, the biological characterization of shielding accentuates features not clearly distinguishable by use of conventional dose equivalent. Biological figures of merit are required for shielding optimization.

1. Strategic Program Plan for Space Radiation Health Research, Life Sciences Division, Office of Life and Microgravity Sciences, National Aeronautics and Space Administration, 1998. http://hacd.jsc.nasa.gov/web_docs/radiation/StrategicPlan98.pdf