What are the Forms of Hazardous Radiation?

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The three main radiation environments of concern on manned exploratory missions are the trapped radiation belts, galactic cosmic rays and large solar particle events. The trapped belts must be circumnavigated as the space vehicle escapes the earth's magnetosphere. Galactic cosmic rays (GCR) are always present and annual doses vary by about a factor of 2 or 3 throughout the solar cycle depending on the amount of shielding available. Large solar particle events (SPE's) pose the greatest threat, but can be shielded against more readily than the GCR because of their softer energy spectra. The earth's trapped radiation belts are relatively well characterized, but dynamic models are needed to better predict doses for escape and return trajectories. For the Apollo missions, the dose was low but measurable from the belts. Risk from GCR doses carry large uncertainties due to the large component of highly ionizing radiation from high energy particles with charge (z) > 2 (denoted HZE particles). On the Apollo missions, no deleterious effects were incurred, but streaks and flashes of light were reported by the astronauts, a consequence of the heavy component of the GCR traversing their retinas. The uncertainty in the biological effects of these particles dominates the cancer risk of long term space missions outside the magnetosphere. A particular concern is risk to the central nervous system (CNS) from these particles, because of the known high density of energy deposition along their trajectories. A vigorous experimental program is underway at the NASA Space Radiation Laboratory (NSRL) on Long Island using the Brookhaven heavy ion accelerator to provide beams of high energy (up to 1 GeV/amu) heavy ions with z up to iron and beyond. Typical effective doses as estimated by NASA at solar minimum (i.e., excluding SPE's) are about 0.07-0.08 Sv for a 90-day lunar mission behind either 5 or 20 g/cm^2 of aluminum. This would produce a predicted radiation mortality probability from cancer for a 40-year old male of about 0.3% (95% confidence limits: 0.1% – 1%) for 5 or 20 g/cm^2 aluminum. The same numbers for a 1000-day mission to Mars with 600 days on the surface are roughly 1 Sv and radiation mortality probabilities of 4.2% (1.3% - 13.6%) and 3.4% (1.1% - 10.8%) for 5 and 20 g/cm^2 aluminum shielding thicknesses, respectively. If a giant SPE like the one that occurred in 1972 is included in these same missions flown near solar maximum, the numbers become effective doses of 0.69 Sv and 0.09 Sv and radiation mortality probabilities of 2.7% (0.95% - 7.6%) and 0.36% (0.12% - 1.2%) for the 90-day lunar mission and 1.24 Sv and 0.6 Sv with radiation mortality probabilities of 5.8% (1.6 – 14.2%) and 2.4% (0.076% - 7.8%) for 5 and 20 g/cm^2 aluminum. For a 40-year old female the mortality probabilities are roughly 20% higher due to the increased probability of radiation-induced breast cancer. The order-of-magnitude variation in the uncertainties reflects high uncertainty in the biological effects of the highly ionizing component of the radiation as well as in the effect of protracting the radiation over the mission duration. Finally, the space physics community can help in a number of ways, including improving the temporal and spatial prediction of large SPE's, both in magnitude and spectral shape, increasing our knowledge of Mars atmosphere composition, improvement of dosimeters which include dE/dx and energy (or velocity) measurements.