CREW HEALTH

23 – Space Radiation

SUMMARY

Space radiation comes in a few different forms. Of greatest concern are the solar particle events (SPE e.g. solar flares) and galactic cosmic rays (GCRs). The equivalent of 20 cm thick of water shielding is sufficient to protect against the short-term death that a very bad SPE can cause. That an ought of shielding can reduce the GCR radiation exposure by about 40% thereby giving crew about six years before they reach their career limit. Add more lunar dirt to the thickness of the habitat and you buy the crew even more time. Crew driving in vehicles will want to carry their SPE shielding with them.

A common concern, and even objection, to traveling and settling down off Earth is the well-known risk of space radiation. We think of space as being empty and it largely is. But, in that void, there are atomic particles and electromagnetic radiation shooting around. This radiation can strike the molecules in our body causing damage. In this chapter, we will consider the different types of space radiation, see what the risks are, and what can be done on the way to and on the surface of the Moon to address this problem.

TYPES OF RADIATION

There is not just one type of space radiation. There is some space radiation that is of little concern. For example, the solar wind is a type of space radiation, but the particles are so small, and their speeds / energies are sufficiently slow such that any spacecraft, habitat, of space suit skin can stop those particles. But there are some that contain sufficient energy to pose a risk.

Trapped Radiation - The Van Allen radiation belts have solar particles that have been trapped by the Earth's magnetic field within bands around the Earth. Whereas this radiation can be a problem if one remains within the belt, if one simply passes through them, the limited radiation exposure is acceptable.

Solar Particle Events - There are times when the sun lets off relatively slow particles but in large quantities in a short period of time. Events such as solar flares and coronal mass ejections fall into this category. Although their energy of each particle is relatively low, because they arrive in such large quantities, they can actually be lethal. And this is not just a hypothetical concern. During the Apollo Program, between Apollo 16 and 17, there were intense solar flares and coronal mass ejections. It is believed that, if the astronauts were in transit or out on the lunar surface when the flare hit, it would have been lethal. Think about how that would have affected the way that we view the Apollo Program now.

Galactic Cosmic Rays (GCRs) - GCRs are the steady "rain drops" of radiation constantly flying through space. Whereas they only occasionally hit astronauts, they can travel at nearly the speed of light and hence cause significant damage including double-stranded DNA damage which is difficult for cells to repair. These are nuclei with masses up to iron side. So each of these heavy nuclei can pack a significant punch.

Secondaries - When something like high-speed, heavy nuclei hit heavier material (e.g. aluminum or regolith), like a game of billiards, the involved nuclei can break apart into smaller elements which continue and can now hit multiple other nuclei. In this way, a single GCR can end up causing a shower of secondaries.

HEALTH EFFECTS

Cancer Risk - The most common concern about radiation is the risk of developing cancer. When radiation hits DNA, it can cause a break. If the break is of a single DNA strand, then the remaining DNA still contains complementary information, and the body has an opportunity to fix the damage. If, however, something like a high-energy GCR breaks both DNA strands, then the body has greater difficulty repairing cells with the lost information. Either way, the risk of cancer increases as the accumulations of mutations withing the cell may cause the cell to start growing in an uncontrolled manner.

In the United States, radiation workers (astronauts are considered to be) have a career limit of no more than three percent radiation exposure induced death (REID). What this means is that radiation exposure should be limited such that there is less than a three percent chance of developing a lethal cancer at some point later in life.

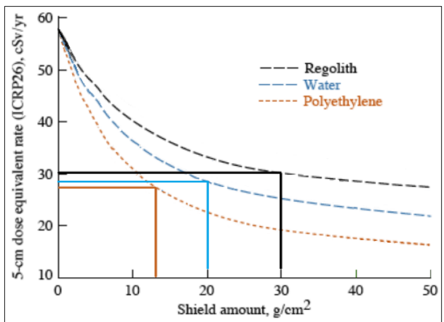
Cell Damage - If a GCR strikes a cell's DNA and disrupts the cell's function, the body will need to replace that dead cell. But certain tissue in the body doesn't replace itself. One such tissue is the brain with its neurons. There are concerns over how much brain function will remain after a 6-month journey to Mars.

SHIELDING

Forms of Radiation Shielding:

Realistically, forms of radiation shielding will include:

- **Water-bearing provisions and waste** - During transit to Mars
- **Regolith -** On top of or within the walls of habitats on the Moon or Mars
- **Water -** In the cab walls of surface vehicles and in the walls of Mars habitats



Adaped from Simonsen, et al. 1997

Applying Regolith

So, how can one cover a habitat with regolith. There are several different possible solutions:

- **Push -** Autonomous tractors can push regolith on the side of the habitat and then drive up on that to push even more regolith on the top of the habitat.
- **Inflate -** If the habitat is inflatable, an even easier approach would be to unfold (e.g. roll out or inflate to unfold) the habitat, have the tractors push regolith on top of the flattened, inflatable habitat, and then inflate the habitat after pushing enough regolith on the top. The upper force of air pressure is far more than the downward weight of the regolith in 1/6th gravity. After inflating, the tractors can then push regolith on the sides. This is an easy approach but does require that the habitats be roughly designed to have flat roofs like air mattresses have.
- **Toss -** Alternately, a "snow blower" type of robotic vehicle could keep driving around the habitat and toss regolith up onto it.

- **Pour -** Finally, robotic vehicles could have a tall conveyor belt / chute that would convey regolith up and pour it into holes at the top of habitats. The holes would be in the outer flexible wall with inner walls being rigidly inflated such that the regolith would slide down between the walls. The result would be an aesthetically pleasing base with the habitats not obviously covered with a bunch of regolith but with all modules having a layer of regolith of set thickness.

CAREER LIMITS

There are several different ways that have historically been used to measure radiation. One of the best ways of measuring it is called Sieverts (daily measured as millisieverts -- mSv). The reason why it is so good is that it includes a biologic adjustment so that different types of radiation have different factors. Certain types of radiation cause more damage compared to other types of radiation even if they have equivalent energy levels.

Radiation limits (to remain within a 3% REID) differ based upon gender and age. For gender, women have sex-specific organ tissue that place them at greater risk of developing cancer. For age, the older one is when exposed to radiation, the fewer years of life remain where cancer can develop before one dies of something else. In other words, older people can be exposed to higher levels of cancer without dying of cancer from that exposure. For convenience’s sake, this book using a reference point of a career limit of 1,000 mSv which fits a 60-year-old male. This is an example of one of the first private individuals who has lived long enough to save enough money to afford to move beyond Earth.

LEVELS IN DIFFERENT SETTINGS

Radiation levels are different at different locations in space when considering shielding (either natural or intentionally applied) as well as the effect of Earth's magnetic field.

Radiation Levels

mSv/ day	Years until 1,000 mSv	Location	Shielding
1.80	1.5	Deep space	No shielding
0.40	6.8	LEO-Inclined	No shielding
0.15	18.3	Equatorial LEO	No shielding
1.80	1.5	EML5	No shielding
1.80	1.5	Transit to Mars	No shielding
1.00	2.7	Transit to Mars	Water*
0.90	3.0	Lunar surface	No shielding
0.73	3.8	Martian surface	No shielding
0.60	4.6	Lunar surface	11 cm regolith
0.50	5.5	Lunar vehicle	20 cm water
0.28	9.8	Martian surface	50 cm regolith
0.15	18.3	Lunar surface	100 cm regolith
0.00	N/A	Lava tube	Thick regolith

* Water-bearing provisions/waste around sedentary areas

Out and About

If a scientist based at the ILB with 100 cm lose regolith and conducts eight hours of scientific exploration per week with 20 cm water shielding around their vehicle's cab, then they would accumulate 9 mSv per year while on EVAs and 55 mSv/day while spending the rest of their time in the base. In other words, radiation exposure during EVAs is a relatively small portion of the radiation exposure due to the relatively small proportion of the time spent on EVAs.

HOW BAD IS IT REALLY?

Sometime space cynics emphasize the risk of space radiation, claiming it to be a showstopper. But to be rational, we need to quantify the radiation using the best means of measuring it, consider reasonable measures that can be applied to mitigate the risk (such as shielding), and then calculate the risks of bad outcomes. Excessive alarmism typically results from the lack of quantification and the assumption of worst case scenarios where no measures are employed to mitigate the risk.

From the chart above, one can gain between three and 18 years of time if applying simple shielding strategies. On the Moon, if one covers an initial lunar base with just enough regolith to protect against solar particle events (i.e. about 30 cm) then one buys themselves 4.6 years before reaching the career limit. During that time, the crew can simply maintain the robotic tractors which can then push even more regolith on top of their habitat. By so doing, the time bought will accumulate faster than time goes by. In other words, they will never have to return to Earth because they have exceeded their radiation limits. So, radiation doesn't appear to be a showstopper from the cancer risk standpoint.

As for the direct cellular death caused by double strand DNA damage, this if more of a concern for a 6-month journey to Mars than a 3-day trip to the Moon. And once on either surface, one can enter a well-shielded habitat largely stopping radiation exposure. So, for the Moon, this isn't a significant concern.

COMPARISON TO OTHER LOCATIONS

The following infographic shows the great difference in terms of radiation exposure between the Moon and the other destinations (LEO and Mars). The reason for this is simple. Whereas the major radiation exposure comes from a short, 3-day trip to the Moon, for Mars, the 180-day trip yields a 60 times greater radiation exposure. As for LEO, as mentioned previously, regular exposure to the trapped radiation of the SAA, long-term residents would routinely accumulate radiation exposure.

AGRICULTURE

Finally, how does radiation affect the way that we grow food?

Like any living thing, plants can be harmed by radiation. However, they are much more radiation-tolerant than animals. However, some solar particle events can be particularly severe such as the Carrington event of 1859. However, at Mars distances, the thin atmosphere, and plant's natural radiation tolerance, it seems as though plant growth would be stunted but they wouldn't be killed. So, it appears as though plants can be grown on Mars in an unshielded greenhouse. Crew working in the greenhouse would increase their radiation risk, but the number of hours needed to reach a REID of 3% means that workers should start in their 50s and they can make it to retirement without reaching a career limit.

However, on the Moon, it is a different matter. Even a moderate-sized solar flare could be quickly deadly for plants. Shielding is essential for the greenhouse. So instead of taking advantage of the direct sunlight, the GreenHabs should be shielded with regolith being the most convenient form available. Greenhouses should best be located at the lunar poles where there are areas of power from nearly permanently sunlight. Whereas light tubes are a somewhat complicated solution, perhaps the better solution would be for solar drapes to collect and convert sunlight into electricity which would be passed though the regolith shielding to optimized (magenta) LEDs to where more than one square meter of plants could be grown using just one square meter of sunlight. During the brief (e.g. 3-4 day night) at the poles, plants could be kept alive with a little amount of magenta light from the LEDs using stored power.