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Cosmic Radiation Raining Down on Earth and Malignancy Nexus

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Abstract**: This document gives information about a special type of radiation which is highly detrimental to human health and terrestrial ecosystem. Cosmic rays are charged subatomic particles. They are electrically charged particles. Cosmic rays are mostly protons and ions, which have positive charges. A small percentage, are electrons, which have negative charges. Cosmic rays pour down on Earth like a constant rain. We don't much notice these high-energy particles, but they may have played a role in the evolution of life on our planet. Cosmic rays are mostly high-energy protons originating from supernova shock waves. It is difficult to precise trace where a cosmic ray came from because its trajectory is bent by magnetic fields. In fact, a typical cosmic ray will bounce inside the galaxy's magnetic field for millions of years before eventually colliding with something… like Earth. Every square centimeter on the top of the Earth's atmosphere is hit by several cosmic rays per second. This is forever going on. None of these "primary" cosmic rays ever reach us on the ground. Instead, they collide with atoms in the upper atmosphere, creating a shower of lower energy "secondary" particles. At sea level, the majority of cosmic ray secondaries are highly penetrating muons. About 10,000 muons pass through our bodies every minute. Some of these muons will ionize molecules as they go through our flesh, occasionally leading to genetic mutations that may be harmful. The passage of a cosmic ray through your body can leave various fluids within your body momentarily ionized.

Keywords: Electromagnetic Radiation**, **Cosmic Rays, Electroscopes, Cosmic Ray Air Shower,** (**CRaTER).

INTRODUCTION

The discovery of these small but energetic particles began accidentally in the early twentieth century when scientists found that their electroscopes could not store charge indefinitely. An electroscope is a device that stores electric charge. It contains a neutral gas to insulate the stored charged. That charge could leak from electroscopes surprised scientists; this meant that the gas was not neutral. Somehow the gas inside the electroscopes was becoming slightly ionized, creating a route to short out the charge. No matter the amount of shielding, such as lead, electroscopes' charge still leaked. A very penetrative type of radiation must have been ionizing the gas It is known that astronomers studying very big things like stars and galaxies. Astronomers also talk about vast distances like thousands of light years. But it is unknown that astronomers also study some of the smallest known objects in the universe. An important example of such tiny objects is the cosmic ray. Even though cosmic rays are small, they are still the most energetic particles in the universe.

Cosmic rays, even though we call them "rays" (like light rays), are not a form of electromagnetic radiation; they are a type of particle radiation. Scientists used that name before they knew what cosmic rays were; some thought that they were high-energy gamma rays. We now know that cosmic rays are charged subatomic particles traveling almost at the speed of light. Most of them are protons, but the name still sticks. Energy in the form of electromagnetic radiation from the stars continually "rains" down on Earth. Similarly, the energy from cosmic rays (particle radiation) is "raining" down on Earth all the time. In addition to being subatomic charged particles, cosmic rays are fast. They are so fast that they travel at almost the speed of light, which is 3×10^8 m/s (fast enough to go around the earth seven times in one second). Most cosmic rays travel at one-tenth that speed. But some have been detected traveling at more than 90% of the speed of light. These cosmic rays have the same energy of a fastball thrown by a major league pitcher. So cosmic rays are charged subatomic particles traveling almost at the speed of light. What makes them move so fast (i.e., have so much energy)? This question continues to puzzle astronomers. Many, if not most, cosmic rays apparently received their "energy boost" when stars much bigger than our sun explode—an event called a supernova. A supernova is one of the most energetic events in the universe. It releases an enormous amount of energy in a short time (more energy than all the other hundred billion stars in a galaxy!); some of this energy can go into boosting charged particles to high speeds. Scientists continue to search for other sources of cosmic rays.

Radiation refers to the emission of energy. There are two types: electromagnetic radiation and particle radiation. Electromagnetic radiation includes radio waves, microwaves, infrared, visible, ultraviolet, X-rays, and gamma rays. Scientists refer to all types of electromagnetic radiation as "light," while most non-scientists use the term "light" to refer only to the visible part of electromagnetic radiation. Energetic particles, which could be protons, ions, or electrons, are types of particle radiation.

Noble prize winner H J Muller found that mutations and changes in human genes can be caused by ionising radiation such as cosmic rays. Therefore it is thought that cosmic rays may be capable of changing your DNA make-up by hitting individual cells, and may even have human evolution implications. However it should be stressed that this is a very rare occurrence as cosmic rays of an energy high enough to cause such changes are rare at ground level higher off the ground cosmic ray radiation becomes more of a problem, indeed astronauts have a problem as the cosmic rays which hit them up in space are generally of a much higher energy than the cosmic rays which reach the ground. The problem arises when high energy electrons (one form of secondary cosmic rays) are stopped suddenly inside the astronaut's spaceship. This produces x-rays which can be harmful to humans if they are exposed to them for any length of time. The astronaut has a couple of options available to him to reduce the radiation which includes wearing a protective spacesuit as well as shielding the spaceship. The lead would be the ideal material for this job, however, it is very heavy and would not be suitable for a spaceship. A substitute for lead, therefore, has to be found, often the fuel stored for use by the spaceship can also be used as a shield. Now the question arises is the energy from cosmic rays much less than, about equal to, or much more than the energy from starlight? The answer is the energy from cosmic rays is about the same as the energy from starlight. The reason we notice starlight more is because our eyes can see the electromagnetic radiation (light) from the stars. Our eyes, however, don't detect particle radiation very well.

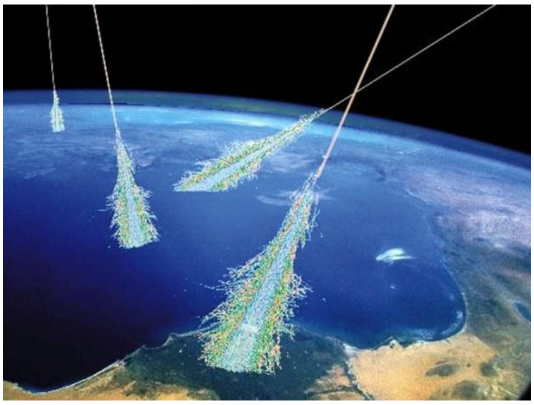


Fig 1: Showers of high energy particles occur when energetic cosmic rays strike the top of the Earth's atmosphere. Cosmic rays were discovered unexpectedly in 1912. Illustration Credit: Simon Swordy (U. Chicago), NASA.

A. HEALTH EFFECTS

The term Radiation means the spread of energy through space or matter in the form of waves or particles. There are two types of radiation:

1. Natural background radiation from cosmic sources (e.g., galactic cosmic rays, solar radiation) and from terrestrial sources (e.g., radiation emitted by rocks, radon)
2. Manmade radiation (e.g., diagnostic X-ray imaging, nuclear reactors)

Now the question arises what kind of radiations human beings are exposed to in space? There are three kinds of space radiation: a) Galactic cosmic rays (GCR) originating outside the solar system; b) Solar particles emitted by the sun during solar flares (solar particle events); c) Radiation trapped by the Earth's magnetic field. On the surface of the Earth, these types of radiation are not significant health hazards because the Earth's atmosphere and magnetic field protect us from most of the radiation from space. Astronauts in low Earth orbit still receive some protection from the Earth's atmosphere and magnetic field, but radiation becomes a much bigger problem when they travel to places outside these protective barriers, like the moon or mars.

Space Radiation is one of the main health hazards of spaceflight. It is dangerous because it has sufficient energy to change or break DNA molecules, which can damage or kill a cell. This can lead to health problems ranging from acute effects to long term effects. The potential acute and chronic health effects of space radiation, as with other ionizing radiation exposures, involve both direct damage to DNA, indirect effects due to the generation of reactive oxygen species, and changes to the biochemistry of cells and tissues, which can alter gene transcription and the tissue microenvironment along with producing DNA mutations. Acute (or early radiation) effects result from high radiation doses, and these are most likely to occur after solar particle events (SPEs). Acute effects such as changes in the blood, diarrhea, nausea, and vomiting are mild and recoverable. Other effects of acute radiation exposure are much more severe such as central nervous system damage or even death. Acute effects are not expected to result from exposure to space radiation, except if an astronaut is exposed to a large solar particle event, such as a solar flare, which produces a high dose of radiation. Likely chronic effects of space radiation exposure include both stochastic events such as radiation carcinogenesis and deterministic degenerative tissue effects. To date, however, the only pathology associated with space radiation exposure is a higher risk for radiation cataract among the astronaut corps.

What can cosmic rays do to the body? Cosmic radiation is ionising, which means the particles involved are energetic enough to knock charged particles from atoms – potentially causing chemical changes in body tissue that can increase risks from cancers and genetic abnormalities. The average person on Earth is exposed to around 350 millirems (mrem) per year. The average annual dose for US citizens is 620mrem, according to the US National Council on Radiation Protection and Measurements. About half of this comes from man-made sources such as X-ray, mammography and CT scans, while the other half comes from natural sources, of which only about 9% comes from cosmic radiation.

Cosmic radiation exposure levels during flights vary according to altitude, latitude and the space weather at the time. Typically, passengers flying from London to Chicago could expect to be exposed to around 4.8mrem, and those traveling from Washington DC to Los Angeles would be exposed to close to 2mrem. This compares to an airport body scanner which delivers around 0.1mrem and a chest X-ray that can vary between 2mrem and 10mrem. Airlines, however, prefer polar routes because they are shorter with lower headwinds, meaning shorter journey times and lower fuel costs. A number of flights from the US to northern Europe and Asia pass directly over the North Pole – for example from San Francisco to Paris. In 2002, Scandinavian researchers analysed data from 10,000 male airline pilots over 17 years and found they were at greater risk of developing melanoma and prostate cancer. However, the charity Cancer Research UK says this may be related to other lifestyle factors such as the pilots spending more time sunbathing than the average person. Two different groups of scientists from Japan and Italy combined their efforts in 2006 to look at health risks to female flight crew members from cosmic radiation. They found that women working on planes were more likely than average to develop breast cancers and melanomas, but again the authors admitted they could not be sure this was to do with cosmic rays. A meta-analysis published last year in the Journal of Radiological Protection concluded that overall cancer risk was not elevated, but that “malignant melanoma, other skin cancers and breast cancer in female aircrew have shown elevated incidence.”

The health threat depends on the flux, energy spectrum, and nuclear composition of the radiation. The flux and energy spectrum depend on a variety of factors: short-term solar weather, long-term trends (such as an apparent increase since the 1950s, and position in the Sun's magnetic field. These factors are incompletely understood.

However, astronomers agree that, if a supernova was to explode within a few light-years from our solar system, then the amount of emitted radiation would be enough to wipe out, directly or indirectly, a significant number of species. “There may have been nearby astronomical goings-on that drastically increased the radiation on Earth,” University of Illinois expert Brian Fields explains. However, he concedes, “Just finding dead beasties is not proof of a nearby supernova.”

Cosmic radiation is made up of high-energy protons, which are mostly generated by supernova explosions and the ensuing shock waves. There is, at this point, no clear way of finding out where they came from, mostly because they are prone to the influence of magnetic fields. This means that they “bounce” inside the galaxy for up to a few million years, before finally making their way to Earth. Still, once here, they usually don't reach the surface. They collide with ions (electrically charged atoms) in the upper atmosphere and break up into a shower of “secondary” particles, which are harmless.

“Every square centimeter on the top of the Earth's atmosphere is hit by several cosmic rays per second. This is forever going on,” Fields explains. Still, a supernova going off just 30 light-years away from the Earth would generate cosmic radiation of sufficient intensity to break through the planet's defenses, and reach the surface, where it would wreak havoc among all living things, from bacteria to humans.

Some theories hold that muons, some of the secondary particles created by broken cosmic radiation, may have played an important part in the evolution of life on Earth. At this point in time, we are subjected to roughly the equivalent of ten chest X-rays of radiation from these fast-traveling particles alone. They can rip ions out of our bodies, which can lead to genetic mutations. “It is very likely that organisms of early Earth possessed DNA that was unstable and could easily mutate under external agents, more so, perhaps, than the DNA of present-day bacteria,” the authors of a new study on the issue, published in a recent edition of the journal Astrobiology, say.

B. HOW TO DETECT COSMIC RAYS

To understand the effects of cosmic rays, we need to be able to detect them. A variety of methods exists. One detector commonly seen and heard, especially in movies, is a Geiger counter (see Figure 2). This instrument can detect various forms of particle radiation and electromagnetic radiation. The sources of particle radiation can be radioactive materials, like uranium, or cosmic rays. The Geiger counter has a small chamber of inert gas. When a photon or subatomic particle passes through the chamber, it can collide with some of the atoms in the gas, stripping them of their electrons. This creates a small current in the gas like the current in electroscopes. The Geiger counter detects the current. If the counter has a speaker, we will hear clicking sounds when the instrument detects radiation.

The Lunar Reconnaissance Orbiter (LRO) carries a detector called the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). Instead of using gas like the Geiger counter, CRaTER uses a solid to detect cosmic rays. It contains six disks made from silicon; they are called solid-state detectors. Such detectors are much more compact than one that uses a gas. A cosmic ray that passes through the detector will create a small current that CRaTER's computer measures. Exposure measurements for cosmic radiation are usually reported in units of microSieverts (mSv). Cosmic radiation exposure measurement and calibration of instruments are complex. Not one device can satisfactorily measure the whole range of particle types or energies because of the random nature of cosmic and solar particle radiation.

Although the cloud chamber seems like a simple device, it was instrumental in discovering new subatomic particles. When cosmic rays collide with atoms in Earth's atmosphere, they create secondary subatomic particles. In 1932, a physicist named Carl Anderson discovered the positron (an antimatter electron, or "electron" with a positive charge) in his cloud chamber. He received the Nobel Prize for this. Anderson next discovered in 1936 a negatively charged particle called the muon. Both particles were the result of using a cloud chamber.

If we could take our cosmic ray detector into outer space, you would see many, many more cosmic rays than here on the ground. That is because the atmosphere shields us from all cosmic rays except for the most energetic. Thankfully, there aren't enough of these really energetic ones to be dangerous to us. Outside the atmosphere, however, there is no protection against any of these particles.

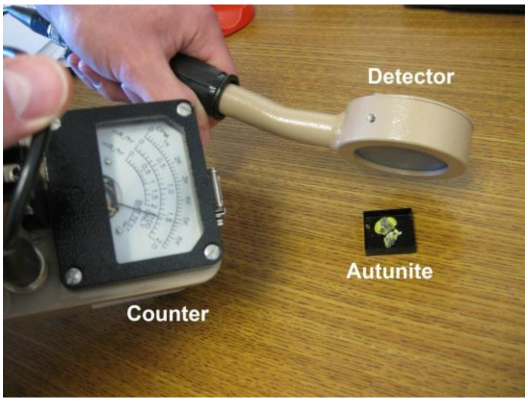


Fig 2 Geiger Counter. The detector in the left hand connects by a wire to the counter in the right. The radioactive source in the small black box on the right is the mineral Autunite, which contains uranium. If we were to move the detector far away from the Autunite, the counter would be very close to zero (but not quite, because of cosmic rays). Autunite, although radioactive, is not dangerous.

C. COSMIC RAY AIR SHOWER

The cosmic rays don't make it all the way down to Earth's surface. They collide with molecules in the atmosphere. These collisions create secondary cosmic rays, which are other subatomic particles with less energy. These secondary cosmic rays can collide with other molecules and create more secondaries, this is a cosmic ray air shower. Showers happen all the time, but they are invisible to your eyes. Figure 2c shows a computer simulation of an air shower. You can find air shower movies at astro.uchicago.edu/cosmus/projects/aires.

D.COSMIC RAY AND ITS INFLUENCE IN CANCER

In the study, the researchers found the trend between cosmic ray increase and cancer death increase was a global effect, but there are places on the Earth where the magnetosphere blocks more of the cosmic rays than others. At about 10°N of the equator, fewer cosmic rays get through than elsewhere on the Earth because of the way the Earth's magnetosphere blocks energetic particles. Cancer does not affect all populations equally nor is cancer rates uniform in time within given populations.

People in more northern and southern latitudes are exposed to more of this radiation, thus the rates of cancer death were higher in these regions than near the equator. On average, the oscillation in cancer deaths was between 10-15% during the period of the study. Previous evidence has implicated a role for cosmic rays in US female cancer, involving a possible cross-generational fetal effect. This study explores the global nature of that effect by examining cancer time variations for population cohorts in five countries on three continents. An understanding of the cosmic ray modulation of life processes is critical to space exploration, evolution, and current medical science. Previous evidence has implicated a role for cosmic rays in US female cancer, involving a possible cross-generational fetal effect. In space, astronauts are exposed to protons and high energy and charge (HZE) ions along with secondary radiation including neutrons and high linear energy transfer (LET) recoil nuclei, produced by nuclear reactions in spacecraft or tissue.

A necessary step for reducing uncertainties in risk assessment are studies on the molecular pathways causative of cancer initiation and progression, and to extend these studies to learn how such pathways can be disrupted by HZE ions including both genetic and epigenetic modifications (figure 2). Biophysical models have shown that the energy deposition events by high LET radiation produce differential DNA lesions, including complex DNA breaks, and that there are qualitative differences between high- and low-LET radiation both in the induction and repair of DNA damage. Complex damage is uncommon for endogenous damage or low-LET radiation and has been associated with the increased relative biological effectiveness (RBE) of densely ionizing radiation. The repair of DSB is known to occur through direct end-joining and homologous recombination processes. Indications are that for high-LET radiation, where complex DSB occur with high frequency, little repair occurs leading to cell death or that the is-rejoining of un-repairable ends with other radiation-induced DSB lead to large DNA deletions and chromosome aberrations. While the high effectiveness in cell killing provides the rationale for heavy-ion cancer 5 Lancet Oncology - Essay therapy (hadrontherapy), residual damage in surviving cells is of concern for carcinogenesis.

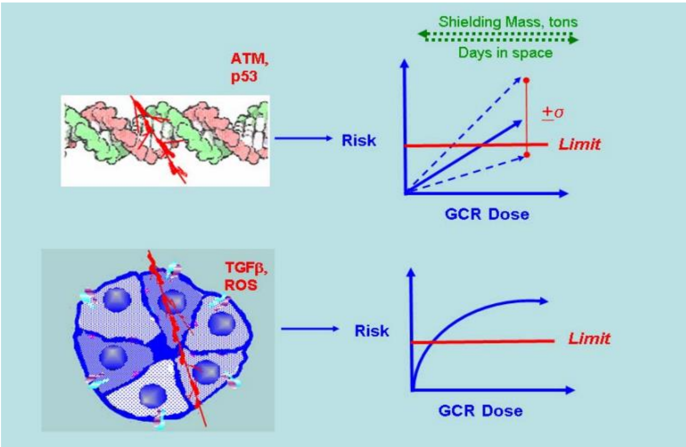
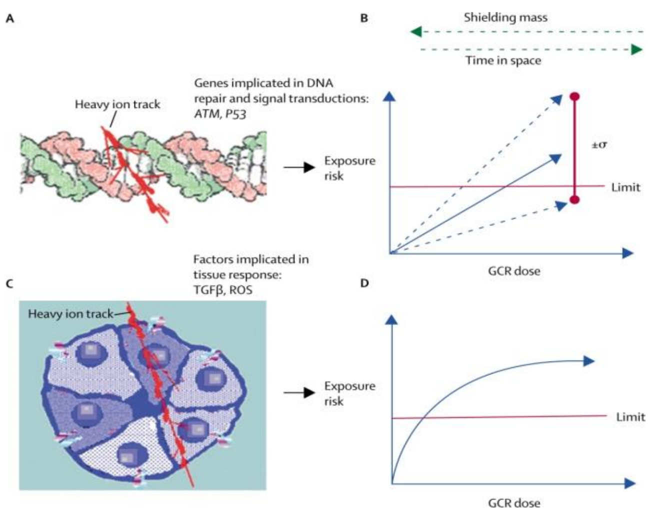


Figure 3. The importance of uncovering basic mechanisms of cancer induction by GCR Defining the role of DNA damage versus that of non-targeted effects has implications for radiation shielding, mission duration, and design of biological countermeasures. In the DNA-target model (A), a linear response (B) for risk is expected, with a research focus on the slope of response as a function of radiation quality and radiation sensitivity ±σ=SE on the slope of the dose-risk relation. Limit=administrative limit that should not be exceeded by astronauts. In the non-targeted model (C), shielding is ineffective in tissue (D) and distinct targets for biological countermeasures are pursued. ATM=ataxia telangiectasia mutated. TGFβ=transforming growth factor β. ROS=reactive oxygen species



Sky and Telescope of July has an article which describes the experiments of Dr. Frank H. J. Figge, of the University of Maryland Medical School, on mice. Male mice were injected with the cancer-inducing substance, methylcholanthrene, and were then distributed in eight cages, five of which were covered with quarter-inch plates of lead. When cosmic rays pass through thin sheets of lead, showers are produced, thus intensifying the effects of cosmic radiation, and the cages were so arranged that various groups of mice were differently exposed to the scattered cosmic radiation during the five months of experimentation. Those so exposed developed tumors in an average period of 8.5 weeks, while 11 weeks were required for those exposed to normal cosmic rays. Other experiments showed the greater susceptibility of mice exposed to cosmic-ray showers. It is true that direct radiation is less effective than secondary showers, but its effect over a lifetime seems to be cumulative. Perhaps architects of the future may be called upon to assist in arresting the development of cancer by choosing building materials which will minimize the effect of cosmic-ray showers.

CONCLUSIONS

Radiation-induced cancer is one of the main health risks for manned exploration of the Solar system. Epidemiological studies on Earth have shown that exposure to moderate to high doses of ionizing radiation increases the risk of cancer in most organs. Leukemia and cancers of the breast, thyroid, colon, and lung are particularly sensitive to induction by radiation. Evidence that cosmic radiation has any effect on fetuses is scanty, researchers say. "The science says that the fetus is particularly sensitive between the eighth and 15th week," says Jacques Lochard, a leader on the upcoming ICRP report. "This is the sensitive period [for] IQ loss." However, several variables influence the intensity of exposure to cosmic radiation. Exposure levels of cosmic radiation increase with higher altitudes and latitudes (poles). Flying at higher altitudes will increase the amount of exposure to cosmic radiation. It is estimated that ionizing radiation exposure doubles for every 4,500 feet of increasing altitude. The earth's strongest protective magnetic field effect is at the equator, thus higher cosmic radiation effects are seen in the polar areas. Radiation doses at polar latitudes can be about twice that at the equator at similar altitudes. The length of exposure is also another important variable. Exposure levels to cosmic radiation have been of increasing concern since the introduction of supersonic transport flights (SST) via the Concorde SST, which entered service with British Airways and Air France in 1969.

Cosmic rays are a unique type of radiation in that they are difficult to shield against. Astronauts are exposed to galactic cosmic rays, the nuclei of atoms careening through space with incredible speed and energy. If they hit an important cellular structure, like DNA, they can generate mutations. Because they move so fast, galactic cosmic rays aren't stopped much by shielding. And there are a lot of them. Out in space, it is estimated that it would take about three days for every single one of our trillions of body cells to be hit by a high-energy proton (the lightest and most common galactic cosmic ray). Over the course of a year, each of our cells would likely have encountered at least one heavy and damaging iron nuclei. Other types of radiation are relatively weak and diffuse, sort of like a BB pellet, making a galactic cosmic ray a cannonball – large, weighty, and packing a punch. And the new research points out that cancer an astronaut could develop after too much cosmic ray radiation is bound to be very dangerous."The type of tumors that cosmic ray ions make are more aggressive than what we get from other radiation," as told by Francis Cucinotta a radiation expert at the University of Nevada, Las Vegas, and author of the new report published Apr. 23 in PLoS One.

However, risk uncertainties for space radiation tumorigenesis are still very high because the radiation quality in space is very different from that on Earth. Reduction of the uncertainties in risk assessment, which are needed for a mission to Mars, has led to many investigations guided by molecular and genetic research on carcinogenesis and degenerative diseases. The main uncertainties in risk-projection models will be reduced only by improvement of basic understanding of the underlying biological processes and their disruption by space radiation. Unique features are involved in this approach because of the specific challenges to biological systems presented by space radiation, especially HZE ions. The issue of radiation risk during space exploration is unlikely to be solved by a simple countermeasure, such as shielding or radioprotective drugs. The risk will be understood and controlled only with further basic research in cancer induction by charged particles. The effects that cosmic rays and other types of radiation have on human beings are important to study, as we venture outside the protective magnetic field of the Earth into space. The researchers said that "this effect has profound implications for evolution, long-distance space travel and the colonization of planets with high background radiation." Long journeys in space would expose astronauts to this same type of radiation for long periods of time, so taking precautions to protect those makes good sense.

One way to reduce astronauts' exposure to galactic cosmic rays could be to send them to space only during the peak of the sun's natural 11-year solar cycle. During solar maximum, the sun's radiation blows counteractively against the cosmic rays streaming into our solar system, reducing an astronaut's exposure. Of course, being in space during this time

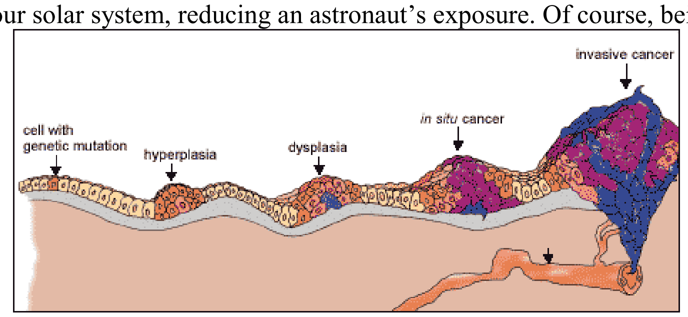


Fig 4: Stages of Cancerous Tumor Development.

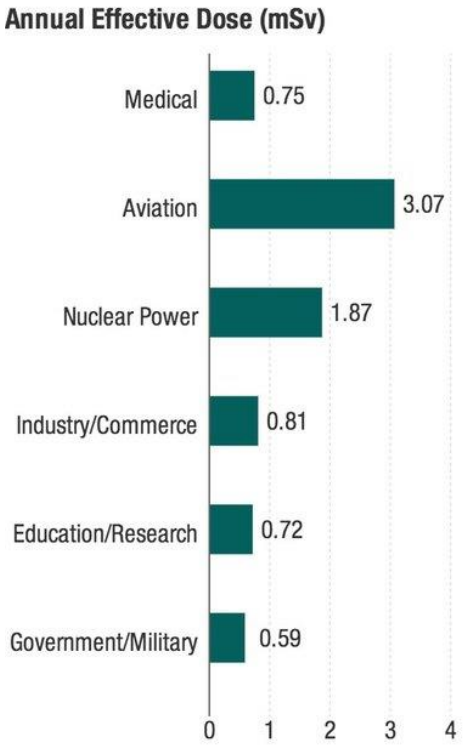


Fig 5: Data from the National Council on Radiation Protection and Measurements show the average annual effective dose for workers in various fields. Aviation doses are estimated based on flight routes and altitudes.*NCRP Report 160*.

Recent studies have found that cosmic radiation percolating down to earth is on the rise; which probably may be the reason for sudden spurt of cancer endangering human species. In summary, the intensity of exposure to cosmic radiation depends on altitude, latitude, the length of exposure, and time of the year (point in the solar cycle or solar flares).

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