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Radiation Effects in Aircraft and the Impact on Human Body

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ABSTRACT

Increasing the plane altitude means an increase in radiationlevel. The International Commission on Radiation Protection (ICRP) identified airline flight crews as a group that is more exposed to radiation, reversing a policy that kept any natural source of radiation free from regulation. Studies have shown that the Radiation doses received by pilots and flight attendants are often greater than those received by traditional radiation workers in the heavily regulated nuclear industry, but, until recently, little attention was paid to occupationally exposed air crew. Scientists usesophisticated equipment allowing them to undertake studies of such radiation exposures, and in some regions of theworld they are trying to monitor air crew radiation exposures during several flights. It will be up to the government, airlines, and air crew to determine what these exposures will mean for the future of air travel and crew safety. High-powered, high-altitude aircraft such as the Concorde or Airbus commonly fly at 55 000 feet, and future aircraft might fly even higher. Galactic cosmic radiation exposure approximately doubles with every 6000 feet of increased altitude. While cosmic radiation poses little or no risk to the "pleasure" traveller, business travellers who log as many hours as air crew themselves could belabelled occupationally exposed. According to the Federal Aviation Administration (FAA) the average radiation dose that is contagious from cosmic and terrestrial radiation is 0.06 microsieverts *(µSv)/hr.* At an altitude of 35 000 feet, which is common for domestic air travel for example from Jeddah to Riyadh, the dose rate from galactic cosmic radiation alone is 6 µSv/hr.

Keywords: ICRP, cosmic radiation, health effects of space radiation, DNA mutations, radiation carcinogenesis and deterministic degenerative tissue effects

What exactly is cosmic radiation?

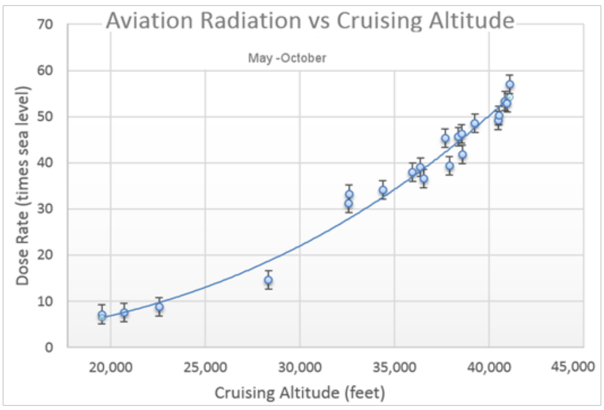

Image 1: Altitude impact on radiation

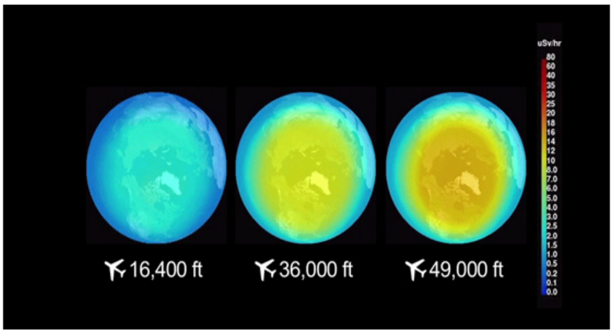

Image 2 : Radiation exposure (source NASA)

Radiation ionised particles (protons and alpha particles) enter Earth's atmosphere, where they collide with nitrogen, oxygen, and other atoms, breaking apart their nuclei. Both the charged particles entering the solar system and the

secondary radiation they produce in the atmosphere are referred to collectively as galactic cosmic radiation. Each disruptednucleus can itself yield multiple ionizing particles, which can interact with other nuclei and produce still more particles, until, after several interactions, they have lost the energy to cause disruptions. The sun is also a considerable source of radiation; solar radiation and galactic cosmic radiation are commonly referred to jointly as cosmic radiation. The effect of the Earth's magnetic field is greatest at the geomagnetic equator, which is located near the geographic equator.
For an example an airplane at an altitude of 20 000 feet at 70° North latitude (near the Arctic circle) would receive galactic cosmic radiation a factor of 2.0 higher than at the same altitude at the equator.
At every latitude, the altitude at which the dose rate is highest is different. The initial interaction of galactic cosmic radiation with the Earth's atmosphere can be so intense that a unique phenomenon is observed at high altitudes above the equator: The intensity of the radiation is lower at 80 000 feet than at 60 000 feet, where particle interactions reach their peak.
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The solar wind (a plasma of solar radiation— mostly protons and electrons—ejected from the sun) carries a convoluted magnetic field throughout the solar system. This wind contains more irregularities at solar maximum, which makes the magnetic field change and become unusually tortuous and strong. Since the ionized particles making up galactic radiation are electrically charged, they can be affected by the highly ionized particles in the solar wind.

Human health 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 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). 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.

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. *The Mars Radiation Environment Experiment* (MARIE) was launched in 2001 in order to collect more data. Estimates are that humans unshielded in interplanetary space would receive annually roughly 400 to 900 mSv (compared to 2.4 mSv on Earth) and that a Mars mission (12 months in flight and 18 months on Mars) might expose shielded astronauts to roughly 500 to 1000 mSv. These doses approach the 1 to 4 Sv career limits advised by the *National Council on Radiation Protection and Measurements* (NCRP) for low Earth orbit activities in 1989, and the more recent NCRP recommendations of 0.5 to 2 Sv in 2000 based on updated information on dose to risk conversion factors. Dose limits depend on age at exposure and sex due to difference in *susceptibility* with age, the added risks of *breast and ovarian cancers* to women, and the variability of cancer risks such as *lung cancer* between men and women.

The quantitative biological effects of cosmic rays are poorly known, and are the subject of ongoing research. Several experiments, both in space and on Earth, are being carried out to evaluate the exact degree of danger. Additionally, the impact of the space microgravity environment on DNA repair has in part confounded the interpretation of some results. Experiments over the last 10 years have shown results both higher and lower than predicted by current quality factors used in radiation protection, indicating large uncertainties exist. Experiments in 2007 at *Brookhaven National Laboratory's NASA Space Radiation Laboratory* (NSRL) suggest that biological damage due to a given exposure is actually about half what was previously estimated: specifically, it turns out that low energy protons cause more damage than high energy ones. This is explained by the fact that slower particles have more time to interact with molecules in the body. This may be interpreted as an acceptable result for space travel as the cells affected end up with greater energy deposition and are more likely to die without proliferating into tumors. This is in contrast to the current dogma on radiation exposure to human cells which considers lower energy radiation of higher weighting factor for tumor formation. Relative biological effectiveness (RBE) depends on radiation type described by particle charge number, Z, and kinetic energy per amu, E, and varies with tumor type with limited experimental data suggesting *leukemia's* having the lowest RBE, liver tumors the highest RBE, and limited or no experimental data on RBE available for cancers that dominate human cancer risks including lung, stomach, breast, and *bladder cancers*. Studies of Harderian gland tumors in a single strain of female mice with several heavy ions have been made, however it is not clear how well the RBE for this tumor type represents the RBE for human cancers such as lung, stomach, breast and bladder cancers nor how RBE changes with sex and genetic background.

Part of the *ISS year-long mission* is to determine the health impacts of cosmic ray exposure over the course of one year spent aboard the *International Space Station.*

However, sample sizes for accurately estimating health risks directly from crew observations for the risks of concern (cancer, cataracts, cognitive and memory changes, late CNS risks, circulatory diseases, etc.) are large (typically >>10 persons) and necessarily involve long post-mission observation times (>10 years). It will be difficult for a sufficient number of astronauts to occupy the ISS and for the missions to continue long enough to make an impact on risk predictions for late effects due to statistical limitations. Hence the need for ground-based research to predict cosmic ray health risks. In addition, radiation safety requirements mandate that risks should be adequately understood prior to astronauts incurring significant risks, and methods developed to mitigate the risks if necessary.

In September 2017, NASA reported *radiation levels* on the surface of the planet *Mars* were temporarily *doubled*, and were associated with an *aurora* 25-times brighter than any observed earlier, due to a massive, and unexpected, *solar storm* in the middle of the month.

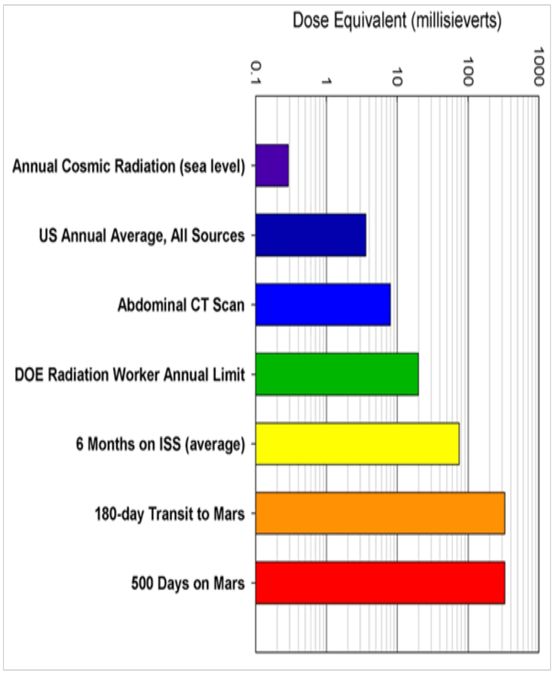

Image 3: Shielding

Material shielding can be effective against galactic cosmic rays, but thin shielding may actually make the problem worse for some of the higher energy rays, because more shielding causes an increased amount of secondary radiation, although thick shielding could counter such too. The aluminium walls of the ISS, for example, are believed to produce a net reduction in radiation exposure. In interplanetary space, however, it is believed that thin aluminium shielding would give a net increase in radiation exposure but would gradually decrease as more shielding is added to capture generated secondary radiation.

Studies of space radiation shielding should include tissue or water equivalent shielding along with the shielding material under study. This observation is readily understood by noting that the average tissue self-shielding of sensitive organs is about 10 cm, and that secondary radiation produced in tissue such as low energy protons, helium and heavy ions are of high linear energy transfer (LET) and make significant contributions (>25%) to the overall biological damage from GCR. Studies of aluminum, polyethylene, liquid hydrogen, or other shielding materials, will involve secondary radiation not reflective of secondary radiation produced in tissue, hence the need to include tissue equivalent shielding in studies of space radiation shielding effectiveness.

Several strategies are being studied for ameliorating the effects of this radiation hazard for planned human interplanetary spaceflight:

• Spacecraft can be constructed out of hydrogen-rich plastics, rather than aluminium.

• Material shielding has been considered:
  - Liquid hydrogen, which would be brought along as fuel in any case, tends to give relatively good shielding, while producing relatively low levels of secondary radiation. Therefore, the fuel could be placed so as to act as a form of shielding around the crew. However, as fuel is consumed by the craft, the crew's shielding decreases.
  - Water, which is necessary to sustain life, could also contribute to shielding. But it too is consumed during the journey unless waste products are utilized.
  - Asteroids could serve to provide shielding

• Magnetic deflection of charged radiation particles and/or electrostatic repulsion is a hypothetical alternative to pure conventional mass shielding under investigation. In theory, power requirements for a 5-meter torus drop from an excessive 10 GW for a simple pure electrostatic shield (too discharged by space electrons) to a moderate 10 kilowatts (kW) by using a hybrid design. However, such complex active shielding is untried, with workability and practicalities more uncertain than material shielding.

Special provisions would also be necessary to protect against a solar proton event, which could increase fluxes to levels that would kill a crew in hours or days rather than months or years. Potential mitigation strategies include providing a small habitable space behind a spacecraft's water supply or with particularly thick walls or providing an option to abort to the protective environment provided by the Earth's magnetosphere. The Apollo mission used a combination of both strategies. Upon receiving confirmation of an SPE, astronauts would move to the Command Module, which had thicker aluminium walls than the Lunar Module, then return to Earth. It was later determined from measurements taken by instruments flown on Apollo that the Command Module would have provided sufficient shielding to prevent significant crew harm. None of these strategies currently provide a method of protection that would be known to be sufficient while conforming to likely limitations on the mass of the payload at present (around $10,000/kg) launch prices. Scientists such as University of Chicago professor emeritus Eugene Parker are not optimistic it can be solved anytime soon. For passive mass shielding, the required amount could be too heavy to be affordably lifted into space without changes in economics (like hypothetical non-rocket spacelaunch or usage of extraterrestrial resources) — many hundreds of metric tons for a reasonably-sized crew compartment. For instance, a NASA design study for an ambitious large spacestation envisioned 4 metric tons per square meter of shielding to drop radiation exposure to 2.5 mSv annually (± a factor of 2 uncertainty), less than the tens of millisieverts or more in some populated high natural background radiation areas on Earth, but the sheer mass for that level of mitigation was considered practical only because it involved first building a lunar mass driver to launch material. Several active shielding methods have been considered that might be less massive than passive shielding, but they remain speculative. Since the type of radiation penetrating farthest through thick material shielding, deep in interplanetary space, is GeV positively charged nuclei, a repulsive electrostatic field has been proposed, but this has problems including plasma instabilities and the power needed for an accelerator constantly keeping the charge from being neutralized by deep-space electrons.

A more common proposal is magnetic shielding generated by superconductors (or plasma currents). Among the difficulties with this proposal is that, for a compact system, magnetic fields up to 10–20 teslas could be required around a manned spacecraft, higher than the several teslas in MRI machines. Such high fields can produce headaches and migraines in MRI patients, and long-duration exposure to such fields has not been studied.
Opposing-electromagnet designs might cancel the field in the crew sections of the spacecraft, but would require more mass. It is also possible to use a combination of a magnetic field with an electrostatic field, with the spacecraft having zero total charge. The hybrid design would theoretically ameliorate the problems, but would be complex and possibly infeasible

Part of the uncertainty is that the effect of human exposure to galactic cosmic rays is poorly known in quantitative terms. The NASA Space Radiation Laboratory is currently studying the effects of radiation in living organisms as well as protective shielding.

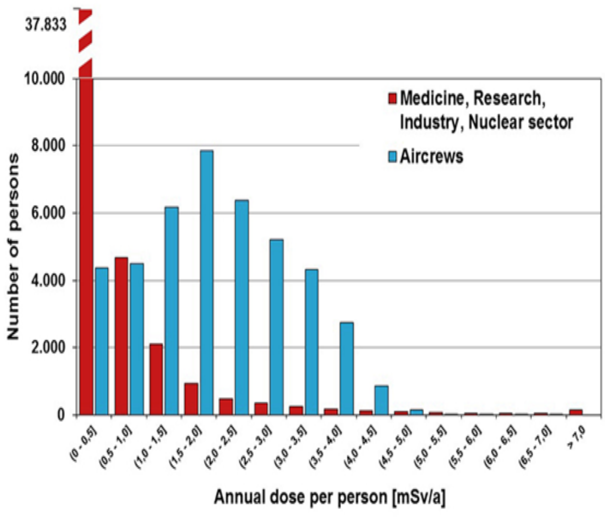

Image 4

Conclusion

Due to the nature of their work, the flight crew is increasingly exposed to radiation as opposed to people who work on the ground. Even though many research on radiation prevention and improving materials and equipment has been conducted, unfortunately, complete protection for people has not been created yet. The consequence of long flights and exposure to cosmic radiation is reflected in faster aging of the organism, continuous fatigue, drowsiness, leading up to the most serious medical conditions such as leukaemia and cancer. In order to avoid this, many airlines restrict flight hours for their employees with the goal to protect their health and ultimately prevent disease occurrence.

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Efekti zračenja u letjelicama i njihov uticaj na ljudsko tijelo

SAŽETAK

Povećanje visine na kojoj se avion kreće predstavlja povećanje nivoa zračenja. Međunarodna komisija za zaštitu od zračenja (ICRP) je identifikovala posadu aviona avio kompanija kao grupu koja je više izložena zračenju, poništavajući politiku prema kojoj bilo koji prirodni izvor zračenja ne podliježe propisima. Studije su pokazale da su doze primljenog zračenja za pilote i kabinsko osoblje često veće od onih koje prime radnici izloženi zračenju u strogo regulisanoj nuklearnoj industriji, ali, sve donedavno, malo se pažnje posvećivalo profesionalno izloženoj posadi aviona. Naučnici koriste sofisticiranu opremu koja im omogućava provođenje studija o takvoj izloženosti zračenju, a, u nekim regijama svijeta, oni nastoje pratiti posadu aviona koja je izložena zračenju tokom nekoliko letova. Na vladama, avio kompanijama i posadi aviona ostaje da odrede šta će ova izloženost podrazumijevati za budućnost zračnog transporta i sigurnost posade. Letjelice velike snage koje se kreću na velikim visinama poput Concorde ili Airbus aviona obično lete na 55 000 stopa, a buduće letjelice bi mogle letjeti čak i na većim visinama. Izloženost galaktičkom kosmičkom zračenju se udvostručuje sa svakim povećanjem visine od 6000 stopa. Dok kosmičko zračenje predstavlja mali ili nikakav rizik za putnike koji putuju iz "zadovoljstva", osobe koje putuju zbog posla, te provedu jednako mnogo sati u avionu kao i njegova posada, bi se mogle smatrati profesionalno izložene zračenju. Prema Federalnoj upravi za civilnu avijaciju SAD-a (FAA), prosječna doza zračenja koja se prenosi kosmičkim i zemaljskim zračenjem iznosi 0,06 mikrosiverta na sat *(µSv/h.)* Na visini od 35 000 stopa, koja je uobičajena za domaći zračni transport, na primjer iz Jeddaha do Riyadha, stopa doze samog galaktičkog kosmičkog zračenja iznosi 6 µSv/h.

Ključne riječi: ICRP, kosmičko zračenje, zdravstveni učinci svemirskog zračenja, mutacije DNA, karcinogeneza zračenja i deterministički degenerativni učinci tkiva

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