Schaefer HJ. ***Evaluation of present-day knowledge of cosmic radiation at extreme altitude in terms of the hazard to health.*** **J Aviat Med 1950; 21: 375–418.**

This Classic paper was the first to recognize and describe the radiation problems of spaceflight, although the subject had been discussed at a meeting on Aeromedical Problems of Space Travel held at the USAF School of Aerospace Medicine in 1949 (1). The conclusion at that meeting was that cosmic radiation was too low in density to have any medical impact. However, that conclusion was based on measurements performed at the Earth's surface. This Classic paper painted a very different picture, using new data from balloon and suborbital rocket flights that showed that galactic cosmic radiation increased rapidly with altitude between the ground and 70,000 ft. The paper also described the recent discovery of the existence of very energetic heavy nuclei particles above 90,000 ft. Dr. Schaefer pointed out that the biological effects of such high-energy particles were unknown and "might become the most difficult problem to be overcome in running manned flights above the atmosphere."

At the time that this Classic was written, the mechanism generating cosmic radiation was unknown, although their omnidirectional nature implied galactic rather than solar origin. Schaefer knew that radiation increased with altitude due to reduced atmospheric shielding and also varied slightly with geomagnetic lattitude due to the Earth's magnetic field. He wrote that the magnetic fields of the Sun and Earth probably had a protective effect and that cosmic rays would have a dose-dependent deleterious biological effect. His measurements showed that cosmic radiation consisted of both protons (80%) and alpha particles (20%), and he assumed that gamma rays would be present in only small amounts. Although the concentration of heavy nuclei was not completely known, it had been measured at just under 1%. This paper showed that the total cosmic ray dosage at high altitudes was 15 mrem/d, which exceeded the human tolerance dosage limit then in use. [Note: In recent years, the Sievert has superseded the rem as the unit of measurement of effective dose, where 1 Sv = 100 rem, 1 mSv = 100 mrem, 1 microSv = 0.1 rem.] The character of cosmic radiation above 90,000 ft was unknown and Schaefer speculated that the levels might be still higher. However, he concluded that "Without a doubt we must not fear that human beings above 90,000 feet altitude will be killed instantly or within a short time. The effect might rather be of the slow accumulating type which makes the clinical picture of the radium poisoning so uncanny and dreadful."

Background

Hermann J. Schaefer, Ph.D., was was a biophysicist who was brought to the U.S. from Germany under Operation Paperclip in 1948. He worked at the U.S. Naval School of Aviation Medicine in Pensacola, FL. His research areas included biophysics, bioradiology, and bioastronautics and he quickly became a leading authority on radiation effects in space.

In this Classic, Schaefer correctly characterized the nature and dosage of cosmic radiation in space, although it was later found that the dose does not increase further above 70,000 ft and that heavy nuclei at this low level would have little biological effect. The later flights of Explorer I, Explorer III, and Pioneer III revealed the protective effect of the Van Allen belts (7), so that spacecraft in low Earth orbit are exposed to only 18–32 mrem/d, depending upon the level of solar activity. Dosimetry on Project Mercury and early Soviet orbital flights confirmed Dr. Schaefer's predictions (2, 3). Gordon Cooper received 31 mrems on his 22-orbit Mercury-Atlas 9 flight and Alexi Leonov received 65 mrems on his 25-orbit Voshkod II flight, which included a 10-min EVA exposure outside of the spacecraft shielding. However, later experiments revealed high levels of cosmic radiation in the South Atlantic Anomaly and the potentially critical levels of radiation produced by solar flares, the latter now a serious concern for long-duration space missions.

Over the next two decades, Dr. Schaefer published multiple papers in this journal concerning spaceflight radiation. He discussed using water or materials with a high hydrogen content (such as plastics) as shielding (4), the somewhat arbitrary setting of the "permissible" dose for cosmic radiation dose (5), the effects of Solar flares (6), the description and protective effects of the Van Allen belts (7), the presence of the South Atlantic Anomaly (2), the need for personal dosimetry during spaceflight (8), radiation monitoring on Mercury and Gemini (2,9) and also future long-duration spaceflights (10). At one time he worried that manned spaceflight might be precluded by high radiation levels during spacecraft passage through the Van Allen Belts without the use of shielding or "polar escape routes" (7). He was also concerned about the extremely high levels of radiation in deep space during an intense solar flare eruption.

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The focus of the far-seeing research by Dr. Schaefer and his colleagues during the 1950s and early 1960s was the effects of ionizing radiation on astronauts and the problems of long-duration spaceflight. Indeed, the health effects of exposure to large particles of cosmic radiation still remain a concern for inter-planetary travel. Schaefer was correct that neutrons are the dominant component of the cosmic radiation field at all altitudes above 10,000 ft. However, it is now known that they are less dominant at lower latitudes, but still contribute 40%–65% of the total dose equivalent rate. Because neutron interactions produce low-energy ions, neutron radiation induces greater biological damage than gamma radiation, although epidemiological data is still sparse.

The Concorde supersonic transport aircraft first flew in 1969, entered service in 1976, and retired in 2003. From the outset it was appreciated that cosmic radiation (both galactic and solar) could present a hazard at the operating altitude of 60,000 ft, as first identified by Dr. Schaefer (11). Accordingly, equipment to monitor ionizing radiation was permanently installed in all Concordes and provided a great deal of data.

Due to the introduction of aircraft capable of ultra long-haul flights in the 1970s, research in aviation medicine addressed the exposure of commercial aircraft occupants to ionizing radiation. Schaefer had shown that protection from cosmic radiation for the Earth's inhabitants is provided by three variables: 1) the sun's magnetic field and solar wind (solar cycle dependant); 2) the Earth's magnetic field (latitude dependant); and 3) the Earth's atmosphere (altitude dependant). Many of the new ultra-long-haul aircraft routes are trans-Polar or trans-Siberian, where geomagnetic and, to a lesser extent, atmospheric shielding from galactic cosmic radiation are less than for routes at lower latitudes. It was only in 1990 that the International Commission on Radiological Protection recommended that commercial aircraft crew members be recognized as occupationally exposed to ionizing radiation and produced appropriate occupational exposure limits. As Schaefer had pointed out, shielding is practically impossible, so commercial aircrew are protected by limiting the period of exposure. Epidemiological data are now confirming that the health risks to commercial aircrew from cosmic radiation are minimal, so the focus is turning once again to spaceflight.

No such limits of time exposure will be possible on future exploration-class space missions such as to Mars. However, in the 1990s, additional

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follow-up and evaluation of the atomic bomb survivor data led to further reductions in the estimated cancer risk for a given dose of radiation (12, 13). Nonetheless there remain large uncertainties in predicting the risks of late effects from exposure to heavy ions, and further research is still needed.

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