SPACE RADIATION DOSIMETRY

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INTRODUCTION

Although partly protected from galactic and solar cosmic radiation by the Earth's magnetosphere in **Low Earth Orbit** (LEO) astronauts exposure levels during long-term missions (90 days to 180 days) by far exceed with exposures of up to more than 100 mSv the annual exposure limits set for workers in the nuclear industry, but are still below the yearly exposure limits of 500 mSv for NASA astronauts. During solar particle events the short-term limits (300 mSv) may be approached or even exceeded.

In the **interplanetary space**, outside the Earth's magnetic field even relatively benign Solar Particle Events (SPEs) can produce 1 Sv skin-absorbed doses. Although new rocket technologies could reduce astronauts' total exposure to space radiation during a human Mars mission, the time required for the mission which is now in the order of years. Therefore mission planners will need to consider a variety of countermeasures for the crew members including physical protection (e.g. shelters), active protection (e.g. magnetic protection), pharmacological protection, local protection (extra protection for critical areas of the body) etc. With full knowledge of these facts, accurate personal dose measurement will become increasingly important during human missions to Mars.

SPACE RADIATION

Charged particles. Usual grouping of the charged particle components of the space radiation [1]:

- geomagnetically trapped radiation,
- solar-particle radiation,
- galactic cosmic rays.

Trapped radiation. As a result of the interaction of particles coming from outer space or the Sun with the geomagnetic field, there are two belts of trapped radiation, the "Van Allen belts", surrounding the Earth as rings in the plane of the geomagnetic equator. Mostly electrons and protons are present in both belts. These particles gyrate and bounce along magnetic-field lines and are reflected back and forth between the two poles, acting as mirror. At the same time, because of their charge, electrons drift eastward, while protons and heavy ions drift westward. Electrons reach energies of up to 7 MeV and protons up to 600 MeV.

For the majority of space missions in lower Earth orbits, protons make the dominant contribution to the radiation burden inside space vehicles. At lower shielding (in the case of EVA – extravehicular activity) the total absorbed dose will be dominated by the electron contribution. Of special importance for low Earth orbits is the so-called "South Atlantic Anomaly" (SAA), where the radiation belt reaches down to altitudes of 200 km. This behavior reflects the displacement of the axis of the geomagnetic (dipole) field with respect to the axis of the geoid, with a corresponding distortion of the magnetic field. This region accounts for the half of total exposure in ISS, although traversing the anomaly takes less than about 15 minutes and occupies less than 10% of the total time in orbit.

Solar-particle radiation. High-energy solar protons and heavy ions, which are among the most severe hazards for manned space flights, are emitted sporadically during solar-particle events (flares). Flares are observed mainly during the solar-maximum phase. Skin doses up to 10 Gy can be reached. On mission outside the magnetosphere, radiation shelters of sufficient thickness must be provided.

Galactic cosmic rays. Galactic cosmic rays (GCR) are charged particles that originate from sources beyond solar system. The GCR spectrum consists of 98% and heavier ions and 2% of electrons and positrons. The ion component is composed of 87% protons, 12% of alpha particles and the remaining 1% heavy ions.

The flux of GCR is affected by the sun's eleven-year cycle. During that period of the solar cycle called Solar Maximum, when solar activity is most intense, the solar wind attenuates a greater flux of the inbound GCR than during Solar Minimum, when solar activity is least intense.

GCR, being composed of charged particles, is also affected by the Earth's magnetic field. Since the geomagnetic field lines are parallel to the Earth's surface around the equator, all but the most energetic particles are deflected away. The geomagnetic field over the North and South Poles points towards the Earth's surface and GCR particles of all energies are funneled toward the poles at high latitudes. The 51.56° orbit of the ISS is sufficiently highly inclined to receive a substantial exposure from less energetic GCR.

Neutrons. High-energy secondary neutrons produced by interactions of high-energy charged particles (from the trapped belts and cosmic rays) contribute a significant fraction of the total dose equivalent in large human spacecraft as the International Space Station (ISS). The two basic components of the neutron radiation are the albedo neutrons emanating from the Earth's atmosphere and the secondary neutrons from the interaction of high-energy space radiation with spacecraft materials. The neutron energy range of interest for radiation risk assessment is 0.1 to at least 200 MeV. Based on both the modelling results and a few measurements covering a portion of the energy range of interest, it was found [2] that secondary neutrons contribute a minimum of additional 30 percent and up to 60 percent of the dose equivalent rates of charged particles.

METHODS TO DETERMINE DOSE

Measurements of dose and dose equivalent of charged particles. Because the radiation field in space is a mixture of different particles, which differ also in energy, and varies with time (all solar cycles are different), it is difficult to calculate doses from earlier measurements.

There are three main methods for the determination of the astronaut's radiation exposure:

1. calculation approach,
2. on-line measurements with active devices and
3. measurements with integrating, passive dosimeters.

Calculation approach. Dose-rate can be calculated from the information delivered on-line by active devices (tissue equivalent proportional counters, silicon detector systems) used as area dosimeters.

On-line measurements with active devices. Active personal dosimeters such as small silicon detectors may be used. Such devices need power. They are well known due to their application in NPPs.

Measurements with passive integrating dosimeters. Passive integrating detector systems such as thermoluminescent dosimeters (TLDs) are commonly used for environmental monitoring and for personal dosimetry. Such TLD measurements need to be supported by spectroscopic information about the high LET part of the radiation field from other instrumentation.

The most known advantages of passive detector systems are their independence of the power supply, small dimension, high sensitivity, good stability, wide measuring range, resistance to environmental changes and relatively low cost. Therefore, they are commonly used for long term measurements from several hours up to months and years.

TLDs are perfect for recording absorbed doses from radiation up to a LET of 20 keV/μm. Above this value the efficiency decreases rapidly with increasing LET. The response function of different TL materials as a function of LET has already been determined through a series of calibration.

TLDs are regularly used on board spacecraft but because of the large dimension and big mass of the readers they are typically evaluated only after their return to the ground. On-ground evaluation has the disadvantage that it results in the dose accumulated since the last read-out i.e. the total dose of the whole flight. Long duration space flights (e.g. on board space stations or at future interplanetary missions) requires time resolved measurements, since this information is needed for radiation risk estimates. A small, portable and space qualified TLD reader suitable for reading out the TL dosimeters on board provides the possibility to overcome the above-mentioned disadvantage.

Since the end of the seventies KFKI AEKI has developed and manufactured a series of TLD systems named "Pille" (Butterfly in English) for spacecraft. The system consists of a set of TL dosimeters and a small, compact TLD reader suitable for on-board evaluation of the dosimeters. By means of such a system highly accurate measurements were and are carried out on board the Salyut-6 [3], Salyut-7 [4], Mir [5, 6] and Space Stations as well as the Space Shuttle. A new implementation of the system is and will be placed on several segments of the International Space Station (ISS) [7] as the contribution of Hungary to the great international enterprise.

The solution of the equivalent dose determination is to combine the TLD reader with an active LET spectrometer like DOSTEL [8].

Neutron dosimetry. The neutron dosimetry on the ISS requests application of a set of different dosimeters:

1. Provide crew personal dosimeters that are sensitive to secondary neutrons in the energy range of interest (0.1 to 200 MeV). At present, the best candidate appears to be CR-39 plastic track detectors. This is a minimum requirement in order to document crew exposure adequately.
2. Develop a proportional counter that would be sensitive only to charged particles and fly it with an existing tissue equivalent proportional counter that is sensitive to both charged particles and neutrons.
3. Develop and fly Bonner spheres with lead (Pb) and iron (Fe) shields to obtain measurements of the high-energy neutron component.

RESULTS OF RADIATION MEASUREMENT

International Space Station. The typical dose rate and dose rate equivalent for 400 km of altitude are equal to 0.35 mGy d^{-1} and 0.9 mSv d^{-1} [9].

The expected average annual dose as a function of flight altitude. For the same circumstances (inclination, wall thickness, orientation, sun activity etc.) the basic component of the dose is the flight altitude. This dependence of the expected annual dose is given in Figure 1.

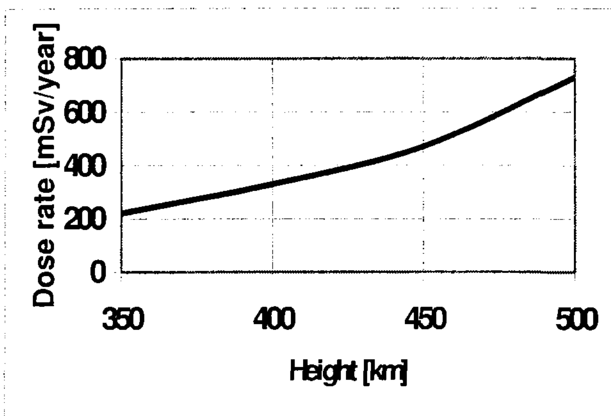

Figure 1. The expected average annual dose as a function of flight altitude for case of orbital stations

DOSE LIMITATION

The new dose limits [10] for radiation workers correspond to excess lifetime risk of 3% (NCRP) and 4% (ICRP). While astronauts accept the whole variety of flight risks they are taking in mission, there is concern about risks that may occur later in life. A risk no greater than the risk of radiation workers would be acceptable.

The actual recommended values for 3% excess lifetime (or career) risk are shown in Figure 2.

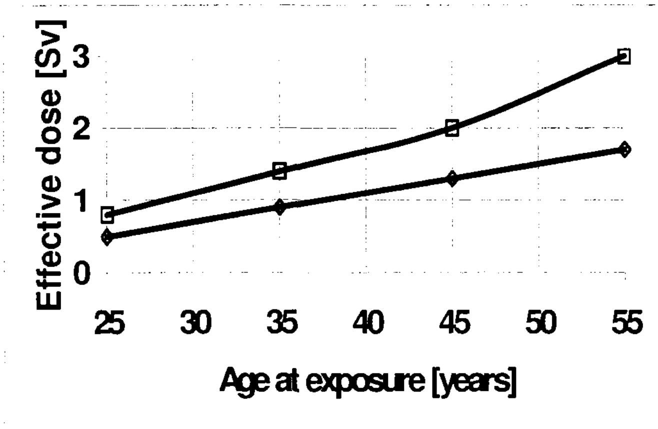

Figure 2. Career limit (Sv) vs. age at exposure □– men, o– women

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