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# Risk Assessment and Late Effects of Radiation in Low-Earth Orbits

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## Abstract

The radiation dose rates in low-earth orbits are dependent on the altitude and orbital inclination. The doses to which the crews of space vehicles are exposed is governed by the duration of the mission and the shielding, and in low-earth orbit missions protons are the dominant particles encountered. The risk of concern with the low dose rates and the relatively low total doses of radiation that will be incurred on the space station is excess cancer. The National Council on Radiation Protection and Measurements has recently recommended career dose-equivalent limits that take into account sex and age. The new recommendations for career limits range from 1.0 Sv to 4 Sv, depending on sex and on the age at the time of their first space mission, compared to a single career limit of 4.0 Sv previously used by NASA. Risk estimates for radiated-induced cancer are evolving and changes in the current guidance may be required in the next few years.

## Introduction

The two major concerns about health effects of long duration space missions are the effects of reduced gravity and ionizing radiation. The experience of the cosmonauts on Mir suggest that the effects of reduced gravity for long periods, such as muscle and bone mineral loss, last a relatively short time. Within weeks of return to Earth full activity appears to be possible. The concern about radiation effects has been muted, in part because the doses incurred have been low even on the Skylab and Apollo missions. The duration of missions even in low-earth orbit, such as on the space station will be much longer than the current shuttle missions. In the future both the number of people in space and the scope of the missions will increase. It is essential to estimate the radiation risks and set limits of exposure of the crews of the space vehicle.

NASA has had a rigorous radiation protection program and in order to update their program they asked the National Council on Radiation Protection and Measurements (NCRP) to reexamine the risks from radiation in space. The complete NCRP report is in press (5) and the major points about career limits have been published (2).

Risk estimates of the late effects of radiation have been made by National and International Committees for many years. The estimates are updated at regular intervals as information and understanding increase. The United Nations Scientific Committee on the Effects of Atomic Radiation (9) have published a major revision of the risk estimates made by UNSCEAR in 1977 (10). The National Academy of Sciences/National Research Council's last report on the assessment of the risks of exposure to external radiation was in 1980 (3) but a new report is eagerly awaited and is expected to appear later in the year.

These more recent risk estimates were not available when the NCRP considered guidance protection limits for radiation received in space activities (5). The aim of this paper is to discuss the estimates of the doses and risk incurred in low-earth orbits that are considered in the NCRP report and what changes in risk estimates of radiation-induced cancer are likely to be made in the next few years.

**Radiation Environment**

In order to make recommendations about radiation protection it is necessary to establish both the dose and the quality of the radiation. In the case of low-earth orbit the radiation environments are well characterized and measurements made on the missions of the shuttle vehicles are in reasonable agreement with the doses predicted by the models.

The three major sources of radiation in space are: the trapped particle radiation in the Van Allen belts, solar particle radiation and galactic cosmic radiation. The major component of the radiation environment in the case of the shuttle missions and the proposed space station is protons. The major source of the protons that have a broad spectrum of energies, is the inner radiation belt. The radiation environments in low-earth orbits are influenced by altitude, orbital inclination and the solar cycle. The total dose equivalent is dependent on the duration of the mission and the shielding.

For the purposes of recommending guidelines for limiting radiation exposures certain assumptions have been made about altitude and shielding. In Table I the daily doses, their source and the daily dose equivalent that are relevant for the space station are shown in order to give an indication of the type of information used by NCRP in making the recommendations (5).

The radiation environments in low-earth orbit are described in detail in this issue (8) and the critical doses for risk estimation are those to the organs at risk and these are also discussed (1).

**Late Effects of Radiation**

For many years, after the mutational effect of radiation was established, the concern about the late effects of radiation centered on genetic effects. Today the major concern is cancer. The effects of radiation are divided into two categories for the purposes of risk assessment and radiation protection, namely, stochastic and nonstochastic effects. Stochastic effects are those for which the probability, but not the severity, increases with dose and are assumed to have no threshold. Stochastic also implies a randomness of the deposition of energy. Nonstochastic events increase both in probability and severity with increases in dose. Cancer and genetic effects are considered stochastic effects whereas skin ulceration is a nonstochastic effect. This classification of radiation effects is more useful than correct. There are lesions, for example, that lead to cataracts and radiation damage to the developing brain that cause mental retardation that do not fall neatly into either category.

When NCRP began its study on "Guidance on Radiation Received in Space Activities" the most recent analysis of cancer risks that had been made was in the development of radioepidemiological tables (7). The NIH analysis differed from previous studies because it not only took into account sex but also age. NCRP used these risk estimates to derive career limits. The stratification on age and sex made it possible to tailor career dose-equivalent limits that were appropriate for radiation protection for the relatively small but special population of astronauts and space workers. A major problem in making recommendations for radiation protection is to agree on what should be considered an acceptable risk. If cancer is a stochastic event there is some risk of mortality from cancer with even the smallest doses. All occupations carry some risk of mortality and in many occupations a significant risk of accidental death is accepted. In agriculture and construction the lifetime risk of accidental death is about 3% and these occupations are not the most hazardous. Space travel has considerable risk and the added risk of cancer must be limited. Cancer is largely a disease of the later years of life and thus the loss of lifespan is usually considerably less than with accidents. With this and other information in mind it was suggested that a career limit based on a lifetime risk of excess cancer of 3% was acceptable. The career dose-equivalent limits shown in Table 2 and Fig. 1 vary from 1.0 Sv for a female exposed first at an age of 25 years up to 4.0 Sv for a male on his first mission at 55 years of age. The previous single overall career limit suggested by the National Academy of Sciences (4) was 4 Sv. Additional limits were recommended by NCRP (5) for nonstochastic effects and reductions were made in the career limits for exposures of the eye and the skin from those recommended in 1970 (4).

**New Risk Estimates**

The latest risk estimates by UNSCEAR, which have just been published (9), take into account the revision in dosimetry at Hiroshima and Nagasaki. However, the major contributors to the changes in the reported risk estimates are the increase in data, especially for survivors that were young at the time of the bombing, and different methods of analyses. A comparison of the estimates made by UNSCEAR in 1977 (10) and 1988 (9) are shown in Table 3. It can be seen that the increase in the estimates of the coefficients of risk has been considerable. The problem with the new estimates of risk is that they are for exposures at high dose rates whereas in space the dose rate or proton irradiation, which is the predominant radiation, is low. It is accepted that the carcinogenic effect at low dose rates of low-LET radiation is less than at high dose rates. UNSCEAR suggests that to estimate risks for low-dose irradiation the risks estimated for high dose-rate irradiation should be reduced by a factor between 2 and 10 but unfortunately gives no further guidance (9).

Within the next couple of years the new risk estimates of UNSCEAR and NAS/NRC (BEIR) V will have been examined critically by national organizations and by the International Commission for Radiological Protection (ICRP). The ICRP, which influences radiation protection standards throughout the world, is currently examining all the evidence from irradiated populations. It will make decisions on how to take into account the effects of dose rate, fractionation , radiation quality as well as the biological factors such as age and sex. When ICRP publishes its recommendations it will be necessary for NASA to determine, in the light of these recommendations, whether any changes in protection standards for the space worker is necessary.

Few things in this world stay the same and radiation protection standards are no exception. The major reasons for change is increased knowledge about risks. The new risk estimates suggest that excess mortality from radiation-induced cancer is somewhat greater than previously thought and therefore a change in terrestrial protection standards are being considered. The possible increase in risk has already influenced such recommendations made by NCRP in 1987 (6) and less formal advice by the National Radiological Protection Board in the United Kingdom. An important caveat is that the current risk estimates are obtained from data for the effects of high doses and high dose rates which do not represent the risks from radiation at the dose rates to which terrestrial and space workers are exposed. A vital question is what dose rate reduction factor should be used.

In summary, in low-earth orbits nonstochastic effects can be prevented completely. With adequate shieldign and rigorous planning of missions over the career of each astronaut and space worker the risk of stochastic effects can be kept to an acceptable level.

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Table 1

Radiation Doses in Low-Earth Orbit

Altitude: 450 km; Orbit: 28½°

Assumptions: (1) 1 gm/cm² shielding

(2) Solar minimum

| Radiation | Dose to bone marrow (mGy/day) |
|---|---|
| Radiation | 0.81 |
| Protons | |
| Inner Van Allen Belt | |
| Galactic Cosmic Rays | 0.045 |

Total dose equivalent ~ 1.09 mSv

dose equivalent in 90 days ~ 0.1 Sv

dose equivalent in 1 year ~ 0.37 Sv

Table 2

Career dose-equivalent limit (Sv) for a lifetime

excess risk of fatal cancer risk of 3%

| Age (yr) at first exposure | 25 | 35 | 45 | 55 |
|---|---|---|---|---|
| Male | 1.5 | 2.5 | 3.25 | 4.0 |
| Female | 1.0 | 1.75 | 2.5 | 3.0 |

Table 3

Comparison of Old and New Estimates of Fatal Cancer
(UNSCEAR 1988)

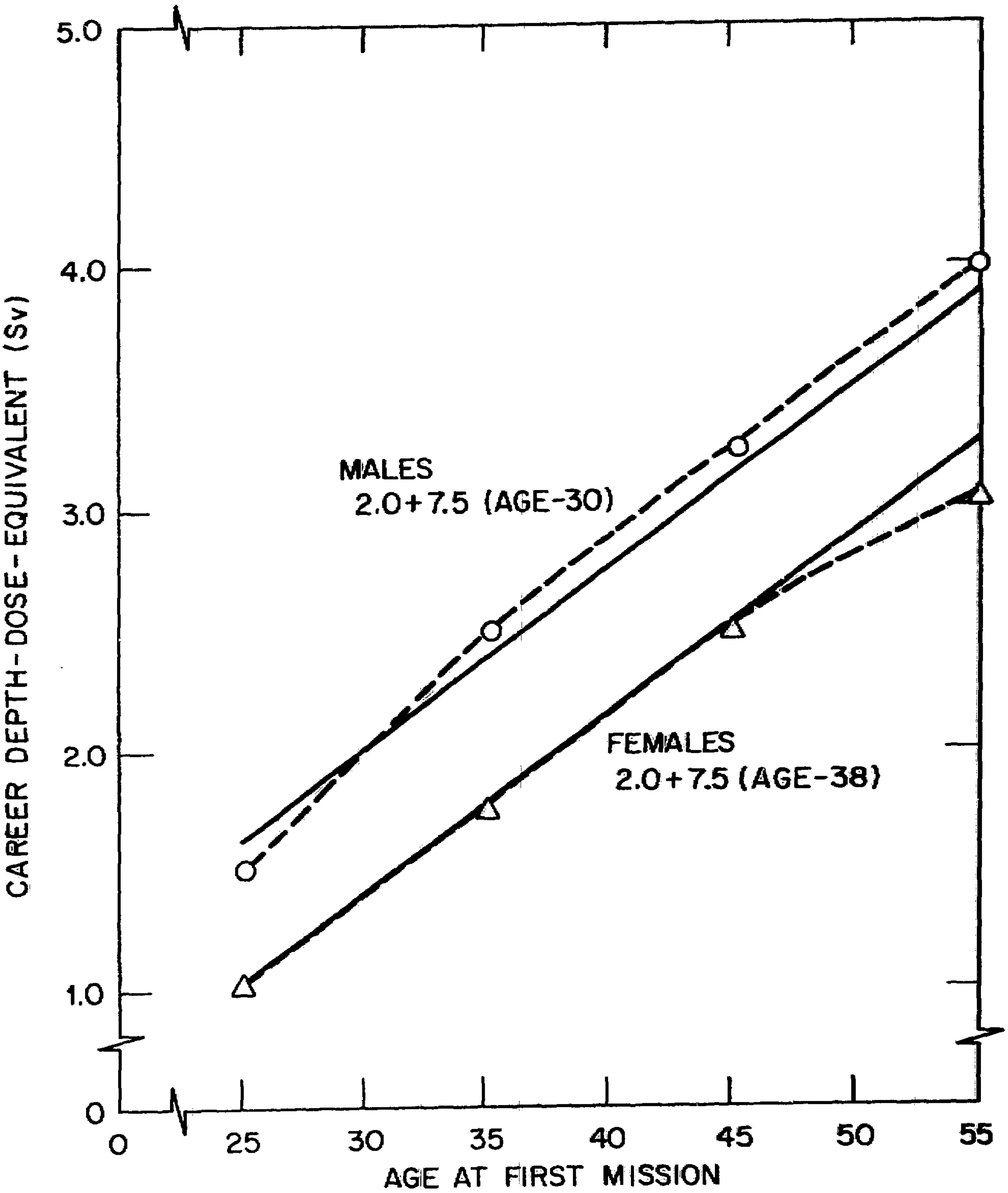
| | Risk Coefficients: 1977 | Percent per Gy 1988 |
|---|---|---|
| Leukemia | 0.2 - 0.5[‡] | 0.7 - 1.3* |
| Total Cancer | 1.0 - 2.5[‡] | 5.5 - 9.1* |

‡ Risk coefficients allow for reduced effect at low doses and dose rates by a factor of 2.5.

* Risk coefficients do not make allowance of reduced effect at low doses and at low dose rates. The estimates are based on data obtained at high doses at high dose rates. In space the dose rate will be low.

## FIGURE LEGEND

Fig. 1. Career dose-equivalent limits as a function of the age at first exposure to radiation in space. Males: 0--0, Females Δ--Δ. Reproduced from R. J. M. Fry and D. S. Nachtwey (2) with permission.


CAREER DEPTH-DOSE-EQUIVALENT (Sv)
5.0
4.0
3.0
2.0
1.0
0
MALES
2.0+7.5 (AGE-30)
FEMALES
2.0+7.5 (AGE-38)
0
25
30
35
40
45
50
55
AGE AT FIRST MISSION