EVALUATION OF RADIATION EFFECTS AND DOSE THRESHOLDS DEFINITION IN THE REMSIM STUDY

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ABSTRACT

Cosmic radiation is a fundamental problem for space exploration. In REMSIM study (funded by ESA in the Aurora framework) strategies have been investigated to protect astronauts from radiation in interplanetary missions. This paper focuses on radiation damage to humans and definition of dose thresholds.

1. INTRODUCTION

Space radiation is one of the most important problems for for long duration manned space missions and human exploration of planet surfaces.

Without the protection of Earth's magnetic field, manned spacecraft for Aurora missions to the Moon and Mars are exposed to extremely higher levels of radiation than in Low Earth Orbit.

Interplanetary mission radiation protection strategies have been investigated in REMSIM, an ESA study led by Alenia Spazio in collaboration with academic (INFN Genova, INFN Firenze, BIRA Brussels), and industrial partners (SME: RxTec Genova and REM Oxford; aerospace: EADS Astrium France and UK).

REMSIM dealt with: radiation environment and its variability, effects on the crew, transfer trajectories to Mars and associated fluencies, vehicle/surface habitat concepts, passive/active shielding, space weather monitoring/warning systems and Geant4 particle transport simulations, thus leading to preliminary dose equivalent estimates.

2. DOSE THRESHOLDS DEFINITION

Exposure to space radiation may produce early deterministic effects from acute irradiation (e.g. SPE: Solar Particle Events) and late stochastic effects from chronic irradiation (e.g. GCR: Galactic Cosmic Rays). A large SPE can deliver > 0.15 Sv/d (Mir crew, 19 Oct 1989); GCR about 0.2–0.3 mSv/d in Mars orbit (Data from the Marie instrument on Mars Odyssey).

The National Council on Radiation Protection (NCRP) set dose limits in Low Earth Orbit (LEO), based on 3% stochastic increase of cancer risk; no limits are set outside the Earth's magnetic field. The unknown late effects from energetic heavy ions carry the largest uncertainty in risk assessment; increase in cancer risk is the main concern.

Due to the lack of radiobiological data (only experiments on Earth, performed with accelerators, and in Earth's orbit are available), we propose the human limits in terms of dose equivalent (Sv), ignoring the precise relationship with the energy delivered by radiation (Gy). Proposed mission limits, valid for males above 35 and females above 45 years, are summarised in the following table:

Tab.1: Proposed dose limits for a mission to Mars

	1 minute	1 hour	1 day	1 month	1 year	mission
Warning	3 *μSv*	0.8 *mSv*	10 *mSv*	0.20 *Sv*	0.40 *Sv*	0.80 *Sv*
Alarm	3 *warnings*	1.0 *mSv*	12 *mSv*	0.25 *Sv*	0.50 *Sv*	1.00 *Sv*

2.1 Mission limits

We propose to set the alarm threshold at 1.00 Sv for the whole mission. This choice derives from the fact that this value is approximately two times greater of the expected mission dose from GCR, and it still allows men above 35 years of age and women above 45 years of age to fulfil the requirement of 3% ERR on the maximum dose that can be received during the whole mission.

Moreover, we propose to introduce a warning dose equivalent threshold, that could be used to initiate countermeasures by the crew (e.g. reduced or no EVA). Considering again the expected dose for the whole mission, we suggest setting this warning threshold at 0.80 Sv, i.e. 20% below of the alarm threshold.

2.2 Annual and monthly limits

In order to allow a better control of the exposure during the mission, we propose to set some operative thresholds for alarm and warning to be applied during shorter time intervals. These values should allow to detect high dose rates that can cause deterministic (short time) effects, although remaining below the mission limits for stochastic effects. While mission limits are based on stochastic effect considerations, shorter time limits shall be based on deterministic effect considerations. As

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already mentioned, to be more conservative, it was chosen to set such limits referring to the most radiosensitive tissues.

For one year and one month, we propose to adopt the organ dose limits suggested by NCRP-132 for protection against deterministic effects of astronauts in LEO missions, and in particular those referred to the most radiosensitive tissues, namely the BFO: alarm threshold at 0.50 Sv for one year and 0.25 Sv for one month. Although they were originally expressed in Gy-Eq, organ dose equivalent limits can be converted into whole-body equivalent doses (in Sv), since they are approximately equal for space radiation applications [1], thus adhering on the most restrictive values. Such conversion allows an easier operational management of dosimetric data with respect to alarm and warning signals, while aiming to keep some safety margin on deterministic effects due to radiation exposure during the mission.

Moreover, as already done for the mission limits, we propose to set a warning threshold at 0.40 and 0.20 Sv , respectively for one year and for one month periods, i.e. 20% below of the alarm thresholds.

2.3 Day and hour limits

With the purpose of monitoring the equivalent dose during astronaut activities during the mission (e.g. EVA), we propose to set some shorter time scale alarm and warning thresholds.

Such levels should be high enough to avoid setting off of false alarms due to random fluctuations in the GCR flux and, at the same time, low enough to allow detecting that a dangerous exposure to ionising radiation has been (or is about to be) reached.

For one day we propose an alarm threshold at 12 mSv and a warning threshold at 10 mSv, such values being respectively 30 and 25 times higher than the average doses due to GCR exposures calculated in the HUMEX study with average homogeneous thickness of 1 g/cm^2 of Al for a 947 day mission to Mars during 1970 solar max (0.4 mSv/d) [2], as well as 20 and 17 times higher than the average doses due to GCR exposures calculated in Benton's study with average homogeneous thickness of 1 g/cm^2 of Al for a 2.5-year mission to Mars during solar max (0.6 mSv/d) [3].

For one hour we propose an alarm threshold at 1.0 mSv and a warning threshold at 0.8 mSv, such values being respectively 48 and 60 times higher than the average doses due to GCR exposures calculated in the HUMEX study with average homogeneous thickness of 1 g/cm^2 of Al for a 947 day mission to Mars during 1970 solar max (0.4 mSv/d) [2] as well as 32 and 40 times higher than the average doses due to GCR exposures calculated in Benton's study with average homogeneous thickness of 1 g/cm^2 of Al for a 2.5-year mission to Mars during solar max (0.6 mSv/d) [3].

2.4 Short-time limits

With the purpose of detecting the fluence rise typical of a SPE, when its contribution to the dose is not yet dangerous but has become quite larger than radiation exposure to GCR flux inside spacecraft, we propose to set some operative thresholds for alarm and warning at very short time intervals.

In the August 1972 SPE, whose calculated average dose equivalent rate to the BFO grew exponentially from 0.1 mSv/h to 1 mSv/h in the first hour, one can set the start time at 54.5 h and the initial dose equivalent rate at 0.1 mSv/h. One can assume that, even during the steep rise of the dose rate at the beginning of the SPE, the dose equivalent rate does not change significantly in one minute. This yields to estimate that the integrated dose after one minute is 0.1 mSv/h × 1/60 h = 1.7 μSv.

The GCR contribution in a minute is approximately 0.6 mSv/d × (1/24 × 1/60) d = 0.4 μSv and, accounting for some 100% fluctuation, it could reach 0.8μSv. Altogether, GCR and SPE would then give an integrated dose of 2.5 μSv after the first minute.

For one minute, being pointless to set a warning threshold that would trigger only seconds before the alarm signal, we propose to set the warning threshold at 3 μSv. In order to get rid of false alarms, we propose to set off the alarm only after three consecutive triggers of the warning condition, i.e. for a cumulative dose higher than 9 μSv in three minutes.

3. CONCLUSIONS

The proposed warning and alarm dose equivalent threshold values are summarized in table 1.

These limits are much higher than the existing ones for radiation exposed workers on earth, but this is unavoidable for a manned, deep space operation like a Mars mission, where a 3% ERR for astronauts due to ionising radiation can be considered acceptable compared with other mission risks.

A proper radiation safety practice should be implemented for manned missions to Moon and Mars: we propose to endorse the NCRP recommendations for LEO, adding the specific requirements for an interplanetary flight.

An algorithm for monitoring radiation and switching warning and alarm messages has been defined and implemented in a demo program.

REFERENCES

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