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LDEF: DOSIMETRIC MEASUREMENT RESULTS (AO 138 - 7 EXPERIMENT)

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SUMMARY

One of the objectives of the AO 138 - 7 experiment on board the LDEF was a total dose measurement with Thermo Luminescent Detectors (TLD 100).
Two identical packages, both of them including five TLDs inside various aluminum shields, are exposed to the space environment in order to obtain the absorbed dose profile.
Radiation fluence received during the total mission length has been computed, taking into account the trapped particles (AE8 and AP8 models during solar maximum and minimum periods) and the cosmic rays; due to the magnetospheric shielding the solar proton fluences are negligible on the LDEF orbit.

The total dose induced by these radiations inside a semi infinite plane shield of aluminum are computed with the radiation transport codes available at DERTS. The dose profile obtained is in good agreement with the evaluation by E.V. BENTON.

TLD readings are performed after flight; due to the mission duration increase a post flight calibration was necessary in order to cover the range of the in flight induced dose. The results obtained, similar (± 30%) for both packages, are compared with the dose profile computation.
For thick shields it seems that the measurements exceed the forecast (about 40%). That can be due to a cosmic ray and trapped proton contributions coming from the backside (assumed as perfectly shielded by the LDEF structure in the computation), or to an underestimate of the proton or cosmic ray fluences. A fine structural shielding analysis should be necessary in order to determine the origin of this slight discrepancy between forecast and in flight measurements.
For the less shielded dosimeters, mainly exposed to the trapped electron flux, a slight overestimation of the dose (less than 40%) appears. Due to the dispersion of the TLD's response, this cannot be confirmed.

In practice these results obtained on board LDEF, with less than a factor 1.4 between measurements and forecast, reinforce the validity of the computation methods and models used for the long term evaluation of the radiation levels (flux and dose) encountered in space on low inclination and altitude Earth orbits.

OBJECTIVE OF THE STUDY

AE8 and AP8 used for the computation of trapped particle fluences encountered in space are steady state models, and of course short term fluctuations cannot be obtained. They come, for the main part, from old measurements performed during the sixties and seventies. Dose evaluations on board STS point out that the use of an updated magnetic field model, taking into account the secular drift, leads to an overestimate of the trapped proton fluence forecast on LEO (ref.1).

The remarks above explain the uncertainties allowed by NASA (ref.2) for the long term forecast of the trapped particle fluence:

- a factor 2 (up and down) for protons,
- a factor 2-3 (up and down) for electrons in the inner zone,
- a factor up to ten for electrons in the outer belt.

An other concern is to define the rate of Single Event Effects (SEE) on electronic devices and the risk of an accute exposure induced by large solar flares during manned missions. For these computations the magnetospheric shielding during solar flares must be well known in order to define the level of transiting radiations, Galactic and Solar Cosmic Rays (GCR and SCR).

On the orbit of LDEF, with an inclination equal to 28.5 degrees and an altitude ranging between 480 km at the begining and 320 km at the end of the flight, the radiations encountered are mainly trapped particles. Due to the orbit inclination the magnetospheric shielding is very effective for the solar protons and the GCR. Concerning the heavy ions from solar events their state of charge is not well known and consequently the magnetospheric absorption cannot be defined.

Significant exposure on board LDEF comes from trapped protons and electrons and the absorbed dose induced by GCR and SCR are weak.

The objective of this study was the evaluation of the doses profiles induced during a mission of some months (mean term) on LEO. Due to the increase of the flight duration the results can be used for a comparison with the long term forecast including solar maximum and minimum periods.

EXPERIMENTAL METHOD

The AO 138 - 7 experiment was part of the FRECOPA tray developed by the Centre National d'Etudes Spatiales (CNES) and set on the row 3 (tray B) on board LDEF.

Dosimeters

Without data transmission, only passive dosimeters could be used. Ten lithium fluoride thermoluminescent dosimeters (TLD 100) were located inside two cases behind various aluminum plane shields (see figure 1)in order to obtain the dose profiles for thicknesses up to 1.08 g/sqcm (0.4 cm of aluminum).

The two dosimeter assemblies were located on the plate supporting the AO138 - 1 experiment ; they are directly exposed to the space environment during all the flight.

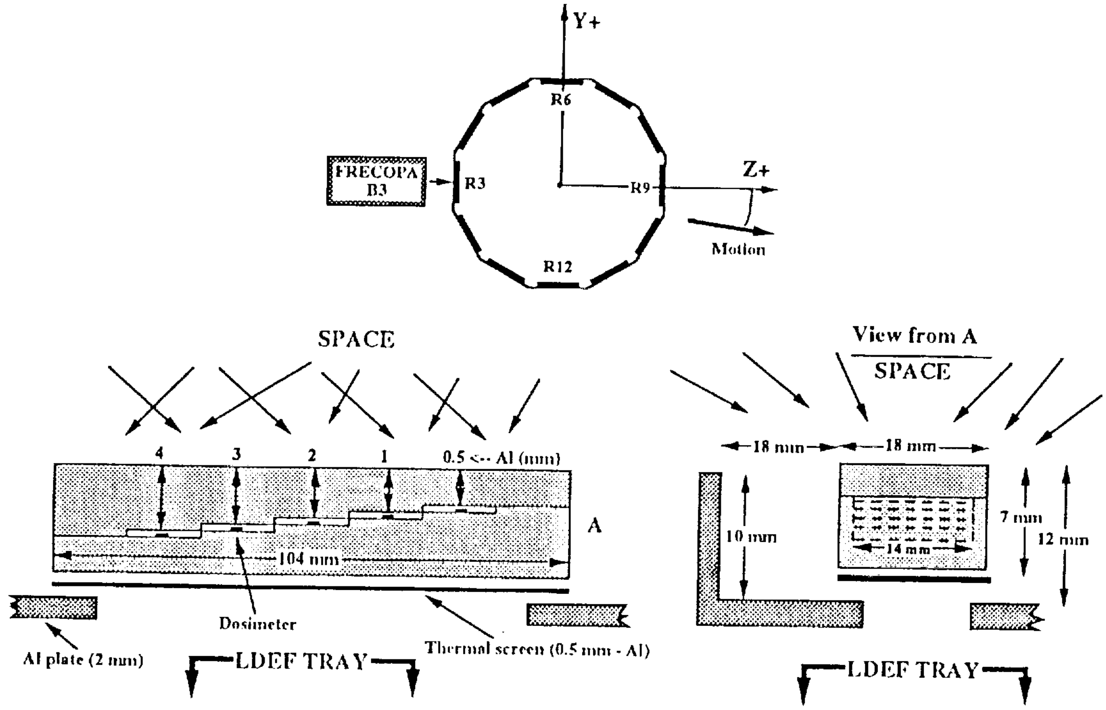

Figure 1 : FRECOPA location on board LDEF and dosimeter assembly

Calibration

The preflight calibration made with detectors of the same set of TLDs (on a range covering the dose expected during the planned mission) cannot be used because of the delayed retrieval of LDEF.

After the post-flight reading a new calibration was performed on all the TLDs used to control their sensitivity in the enlarged domain of dose obtained during the LDEF mission.

FLUX AND ABSORBED DOSE FORECAST

The flight of LDEF, from April 1984 to January1990, extends approximately over half part of a solar cycle, with a minimum of activity observed in September 1986.

GCR and trapped particle fluences are determined assuming that the first four year period was during solar minimum; the end of the flight (about 10 months) was during solar maximum.
The AP8 and AE8 environment models are used,with solar maximum and minimum conditions, for the evaluation of the trapped particle fluences. In the code available at DERTS for these computations (ref.3), following NASA recommendations, the magnetic field model is not updated and fits the conditions encountered at the epoch of the measurements.
Concerning GCR fluence evaluation, the models for solar minimum and maximum periods are those developed by DERTS from the data of JP. Meyer (ref.4). The magnetospheric shielding is included in the computation (DERTS code BLINMAG).

In order to take into account the altitude change during the mission the computations are performed for the inclination 28.5 degrees and four steps of altitude:

- 475 km, from the mission begining up to the day 1000,
- 470 km, from day 1000 to day 1500,
- 440 km, between day 1500 and 2000,
- 330 km, from day 2000 to the retrieval.

The absorbed dose profiles, D(x), induced by the trapped particles and the GCR , are computed at a point tissue sample at depth x inside an infinite plane shield of aluminum. Isotropic distributions are assumed for the radiations impinging the shield. Straight ahead approximation is used for protons and other ions; scattering is taken into account for electrons and the bremsstrahlung induced dose computed is negligible.
The dose profiles obtained with our codes (ref.5) for trapped protons and electrons (see figure 2) are similar to the results reported by EV. Benton (ref.6).
Due to the orbit inclination the protons from solar events (October 89 for instance) are unsignificant, and the doses due to GCR are negligible for the shield thicknesses studied.

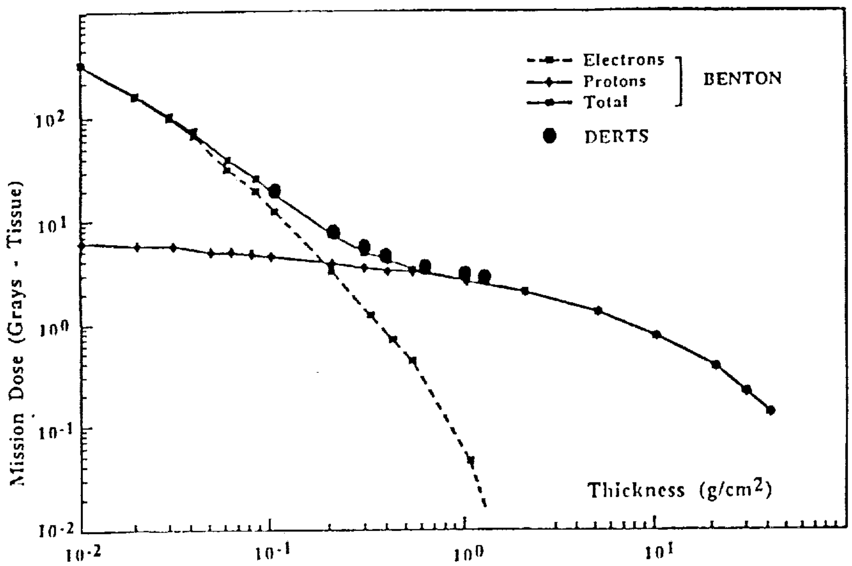

Figure 2 : Dose profile forecast, for tissue inside an infinite plane shield

LDEF MEASUREMENTS

The results obtained (see figure 3) on the FRECOPA tray agree with both dosimeter groups for shield thicknesses above 0.5 g/sqcm; due to energetic trapped protons the dose profile is then relatively flat (between 3 and 4 gray).

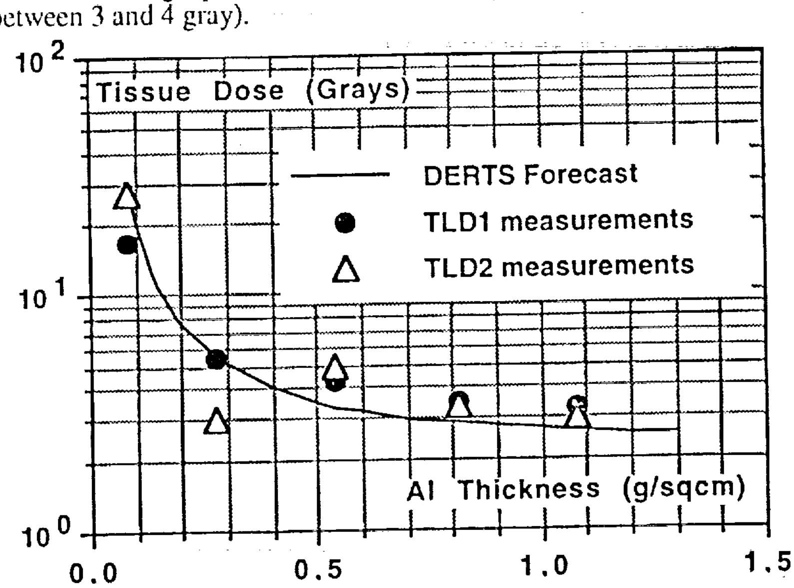

Figure 3 : TLD measurement results, comparison with the computation

A good agreement (difference about 20% for the point 0.7 g/sqcm) is observed with the measurements performed by G. REITZ (see figure 4) in the BIOSTACK unit (location: C2, near the FRECOPA tray).

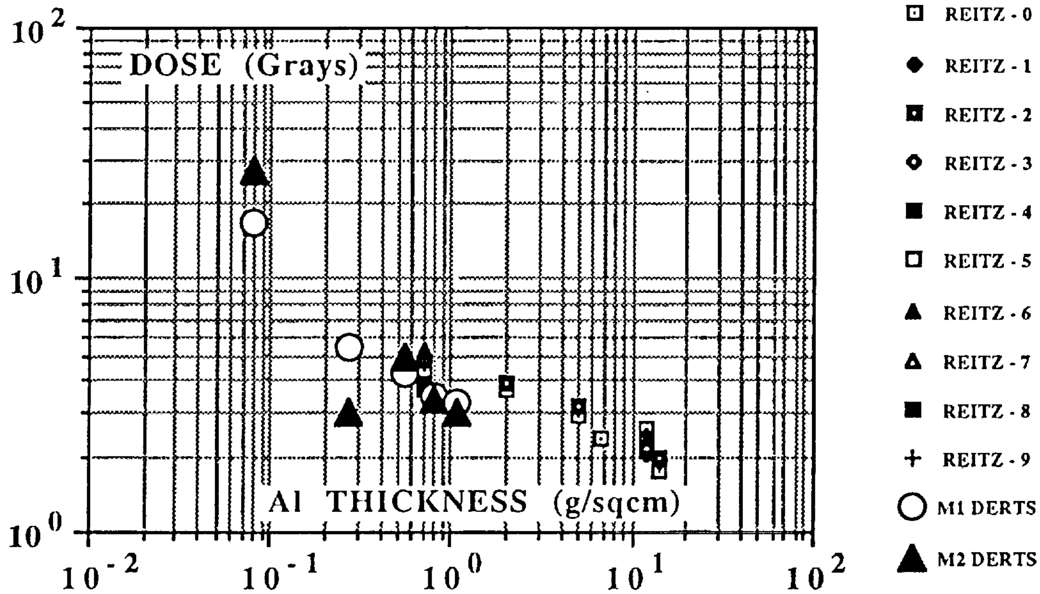

Figure 4 : In flight measurement, comparison with results reported by G. REITZ (ref.7)

For thin shields (0.081 and 0.27 g/sqcm) the dose is mainly induced by trapped electrons, and larger dispersions (20 and 30 %) are observed between the two groups of TLD of our experiment.

In spite of rough descriptions (two and four steps respectively) of solar activity change and altitude decrease during the mission, there is a general agreement between measurements and simple plane shield geometry calculation.

For thick shields (0.55, 0.81, and 1.08 g/sqcm) the differences between forecast and measured doses indicate an under-estimate (20 to 30%) of the computed values, that may be from the AP8 models, but in this case the unaccuracy announced by NASA (factor 2) appears as pessimistic. Increases of doses for thick shield can be also due to:

- primary particles from the lateral and back sides of the TLD case,
- secondaries (neutrons, protons, etc) produced in the structures,
- the anisotropy of the incident radiations (mirror points).

For thin shields (0.081 and 0.27 g/sqcm) the dispersion of the measurements (± 20 and 30 %) and the differences with previsions are of the same order of magnitude; however, it seems that computations overestimate (less than 50 %) the electron induced dose.

CONCLUSION

The part of the AO138-7 devoted to dosimetric measurements on the FRECOPA tray on board LDEF, with differences smaller than 50% between forecast and measurements, generally confirms the validity of:

- the NASA models AP8 and AE8 used for the computations of trapped particle fluences encountered in LEO during more than half of a solar cycle,

- the codes developed to simulate the particle transport in matter, and to determine the absorbed dose, at least for plane shield, and thicknesses smaller than 1.1 g/sqcm.

These conclusions concern long term missions on low altitude and weakly inclined orbits. They are not valid for many application satellites, particularly in GEO, where an overestimation of the electronic doses and an unexpected effect of the solar activity are evidenced (ref.8).

The LDEF mission demonstrates the interest of in-flight passive (if retrieval) or active dosimetry in order to study various unsolved problems as:

- the validity of the long term forecasting methods for inclined LEO and GEO (trapped particles, solar events and GCR),
- the consistency of the doses that can be computed and measured inside the complex structures of a space vehicle,
- the short term fluctuations of trapped particle populations linked with variations of geomagnetic activity, problem concerning mainly, as the solar flares, the manned space missions.

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