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ONBOARD MEASUREMENTS OF COSMIC-RAY INDUCED DOSE ON AIRCRAFT IN BRAZILIAN AIRSPACE

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ABSTRACT

Since 1990, the International Commission on Radiological Protection (ICRP) recommendations consider cosmic radiation induced doses as occupational exposure for some aircrew members. According to the ICRP 60, an aircrew member, who is subjected to more than 1 mSv accumulated dose in one year, should be treated as an occupationally exposed worker. The radiation doses received by aircrew are produced by secondary and tertiary particles and photons, produced by interactions of primary cosmic rays within the atmosphere. Neutrons are responsible for up to 40% (60% at high latitudes) of these doses. Moreover, the increasing miniaturization of electronic components, already in sub-micron scale, has caused a significant increase in their susceptibility to the effects of ionizing radiation, in particular the so-called “Single Event Upsets” (SEU), produced by neutrons in onboard computers, that could compromise flight safety. The dose rate is dependent on latitude, altitude and space weather. Measurements were taken with active and passive detectors specially calibrated for the field of cosmic radiation present at flight altitudes. Such equipment was supplied by Institute of Advanced Studies (Brazil), and collaborators from QinetiQ (United Kingdom) and Milan Polytechnic Institute (Italy). The preliminary results of the measurements are expressed in Ambient Equivalent Dose (H*) and are compared with those results of computational codes used to estimate aircrew dose. The experimental flights were made on a flight test aircraft from the Brazilian Air Force up to 12,000 m.

1. INTRODUCTION

The ionizing radiation dose level received by aircrew members and electronic devices during air travel have become increasingly important in recent years, which can be demonstrated due to a growing number of studies and publications in various fields such as occupational health, radiation protection, safety of flight among others [1,2,3,4].

As the dose rate of cosmic radiation (CR) increases with altitude, it provides conditions where aircrew members often exceed the annual limit proposed by international organizations for individuals of the public, defined by the International Commission on Radiological Protection (ICRP) as 1 mSv [5].

The group of flight professionals (cabin crew members and pilots) is exposed to radiation levels as much as the groups of professionals that work with radiation in medicine and technology [3]. In 1990, it was proposed by ICRP 60 that the group of flight professionals should be properly considered as individuals occupationally exposed to ionizing radiation. This recommendation was later described in more detail in subsequent recommendations [6,7]. These recommendations were later adopted by the European Union and Canada.

The cosmic radiation is composed by high energy charged hadrons. The interaction with the atmosphere and the earth magnetic field produces secondary radiation, mainly neutrons and muons.

In the case of Brazil, most of its area, especially the southeast region, is under the effects of a magnetic anomaly of origin that is not fully known, called the South Atlantic Anomaly (SAA) [8, 9]. This anomaly changes the way that cosmic radiation interacts with the magnetic field and the atmosphere, which shows the need of more studies and more detailed dosimetric assessments.

The increasing number of recent publications shows that this issue has gained prominence in the international scientific community. Nevertheless, most experimental measurements of cosmic radiation were carried out in the northern hemisphere, specifically in the North America and Europe regions, and few data were acquired in South America region, especially in the SAA region.

The Brazilian Commission of Nuclear Energy (CNEN), in its basic guidelines for radiation protection, normative act NN-3.01, defines as "individuals occupationally exposed" (IOE) the individuals subject to occupational exposure, i.e., subject to normal or potential exposure due to work or training in permitted practices or interventions, excluding the natural radiation of the site [10]. This rule defines also the "Natural Sources" as radiation sources that naturally occurring, including cosmic and terrestrial radiation. There is no mention of flight professionals, i.e., pilots and aircrew in general.

It is also important to mention the lack of consolidated scientific groups in South America that have relevant experience and specific publications on this subject.

2. MATERIALS AND METHODS

2.1. Equipments

The onboard dose measurements were taken by means of two active systems and one passive dosimeter, specially calibrated for the radiation field of aircraft flight. The calibration of all equipment was made with conventional radiation sources and, in order to ensure an appropriate response for the field at aircraft altitudes, was verified in the Cosmic Energy Reference Field (CERF) at CERN (*Centré European de Recherché Nucleaire*). CERF is a special field from a CERN's facility wich reproduces the shape of field present in atmosphere at aircraft altitudes with great similarity [11].

There was a GPS system (DATUM WGS84), specially set up for this experiment, to give the correct position and altitude of the flight.

2.1.1. Active detectors

The first active system (RaySure™) is a silicon-based dosimeter, developed at QinetiQ and specially designed for measurements on aircraft (Fig 1). The system is made using PIN type silicon diodes and was previously characterized for this type of fields [12, 13], allowing to obtain the results directly in Ambient Equivalent Dose quantity, which is the recommended quantity for this type of measurements. The RaySure™ system uses an autonomous power source and the results are obtained in time intervals defined by user and stored in an internal memory, which can be subsequently collected by the user.

Figure 1. Monitor RaySure™ (previously known as QDOS) [12].

The second system is the THERMO SCIENTIFIC monitor that consists of an acquisition electronics model FH40G-10, with remote acquisition capabilities, programmable by PC, and up to two probes. The system has an internal proportional counter and allows the connection of an external probe with simultaneous acquisition. It was projected and calibrated to present the results directly in the operational quantity Ambient Equivalent Dose and stores the values in an internal memory which can be subsequently collected by the user. As external probe, we used one THERMO FHT 762 neutron probe, which consists of one ^{3}He proportional probe inside a cylinder made with tungsten and polyethylene layers, projected to obtain the response according to Ambient Equivalent Dose for neutrons up to 5 GeV [14]. The system can be viewed on Fig 2.

Figure 2. Monitor FH40G-10 with FHT-762 neutron probe [14].

2.1.2. Passive dosimeter

The passive dosimetric system, developed on Milano Polytechnic Institute [15,16], consists of one SSNTD (Solid State Nuclear Track Detector) of CR39 PADC (Poly-Allyl-Diglycol-Carbonate), coupled to a ^{10}B enriched converter, positioned inside a sphere made with polyethylene, lead and cadmium, as can be seen in Fig 3.

Figure 3. Passive dosimetric system, based on CR39 PADC on polyethylene/lead sphere.

The system is based on tracks generated in CR39 PADC by alpha particles from (n,α) reaction on ^{10}B, and its calibration for neutron radiation was previously done on CERF field, for the quantity Ambient Equivalent Dose (H*(10)).

2.2. Aircraft and mission

The flight measurements were carried out in March 2011 on board a Learjet-type aircraft from Brazilian Air Force in a nearly straight route inside Brazilian territory, from São José dos Campos (SP) to Recife (PE) and returning by the same path (Fig 4). The latitude of the route varied from 23.2^{o} S to 8.1^{o} S and the magnetic rigidity varied from 9.6 GV to 11.7 GV. The medium flight level on route SJC-Recife was approximately 33000 feet (FL330) and the return flight, Recife-SJC was performed at approximately 39000 feet (FL390).

Figure 4. GPS log of the flight from São José dos Campos (SP) to Recife (PE).

2.3. Computational dose estimation

The computational estimated dose in flight was performed using the computational codes QARM and CARI-6.

QARM code uses a dynamic cosmic ray radiation model and a data base from a response matrix, generated from Monte Carlo calculation of cosmic radiation propagation in the atmosphere. This code can be accessed on-line [18], and the interface with user allows several types of calculations. In this work we used the flight dose calculation option, where the user inputs the following information: the departure and arrival coordinates or airports, flight time, altitude and Kp index. The Kp index is an geophysical index related to measure the perturbation degree of Earth magnetosphere. The results of QARM code are expressed both in effective dose and ambient equivalent dose, where the last one uses the conversion factors obtained from ICRP 74 [17].

The CARI-6 code is based on the LUIN code [19,20] and calculates the total effective dose between depart and arrival airports using data from altitude, time and a heliocentric potential.

3. RESULTS

The ambient equivalent dose rate was fully recorded during the flights with FH40G-10 monitor. The results of H*(10) rate are presented on Fig 5 for the flight from São José dos Campos (SP) to Recife (PE) and in Fig 6 for the return flight from Recife (PE) to São José dos Campos (SP).

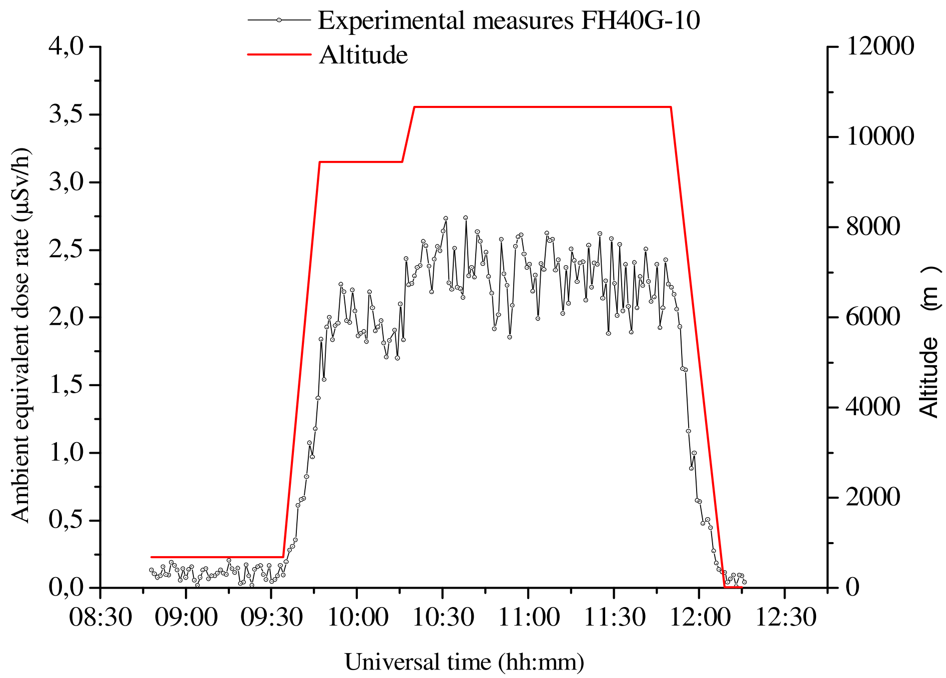

Figure 5. Dose rate and altitude profile for the flight from São José dos Campos (SP) to Recife (PE).

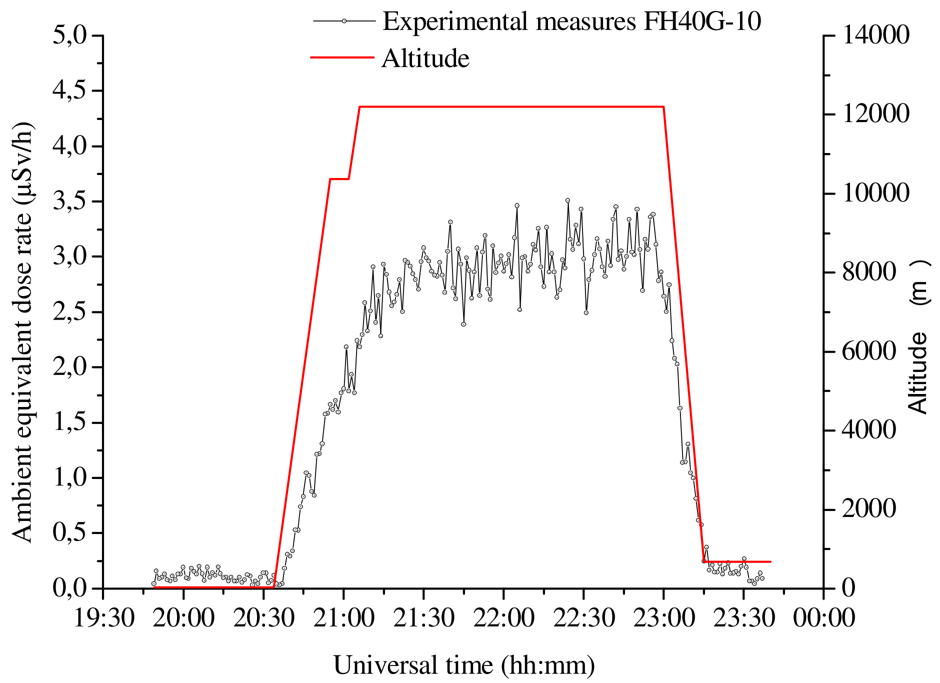

Figure 6. Dose rate and altitude profile for the return flight from Recife (PE) to São José dos Campos (SP).

In Fig. 5 we can clearly see one dose rate step produced by the altitude change. In the same figure we can observe the decreasing behavior produced by gradual increase of magnetic rigidity cut-off. On the other hand, the Fig 6 shows a dose rate increase produced by the decrease of magnetic rigidity cut-off.

The total dose from each leg of the flight is shown in Fig. 7 and Fig. 8. In the same figures we can see the results from estimated doses obtained from QARM and CARI-6 codes. The results from CARI-6 code, in effective dose quantity, were converted to ambient equivalent dose quantity using interpolation based on the conversion factors suggested by ICRU 84 [21]. The experimental uncertainties were expressed with k=1 confidence interval.

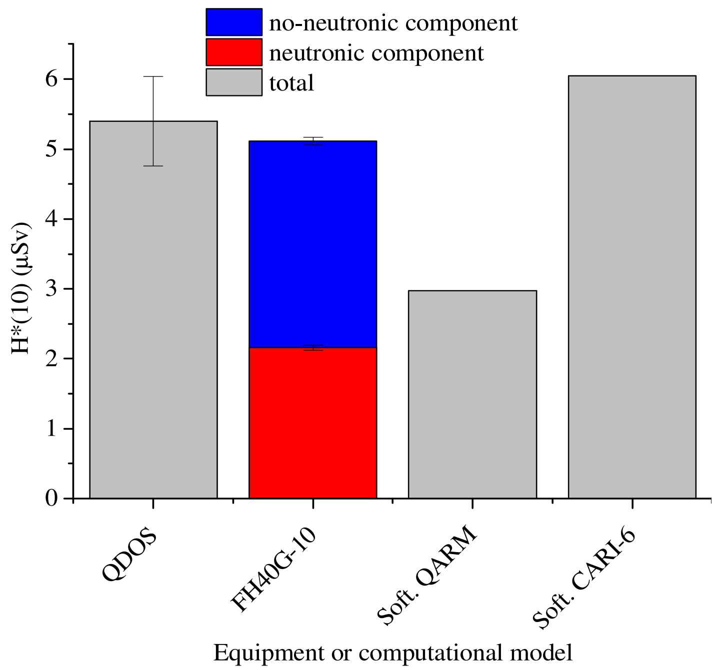

Figure 7. Comparison of results of total dose for the flight from São José dos Campos (SP) to Recife (PE).

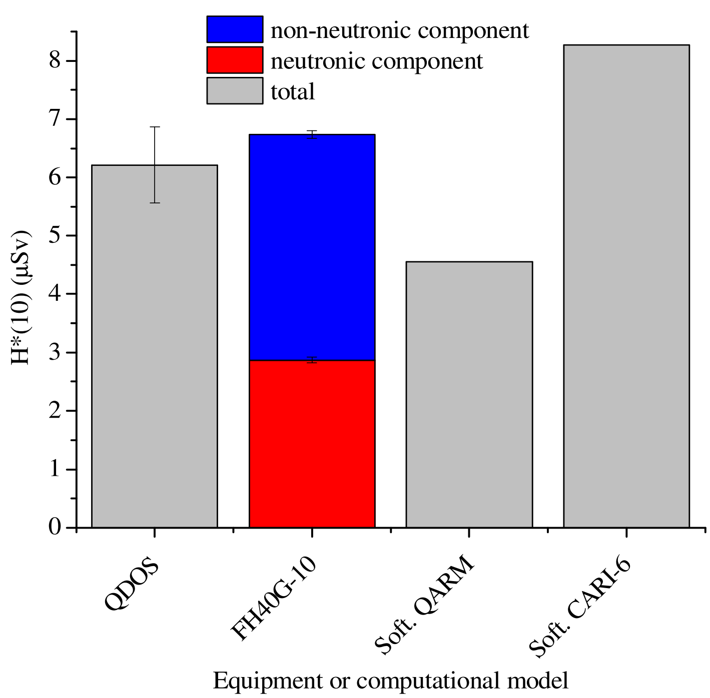

Figure 8. Comparison of results of total dose for the return flight from Recife (PE) to São José dos Campos (SP).

From Fig. 7 and Fig. 8 can be seen that the difference between results is less than 11% and within one standard deviation, which agree well with the 15% typical differences on experimental measurements that is cited on ICRU 84 report [21].

The maximum differences between medium experimental values and computational estimative values are about 64%. The results from CARI-6 code systematically overestimate the experimental ones and the reasons for these differences need to be further investigated. The results from QARM code underestimate the experimental ones, but part of this under estimation is due to a known behavior for low latitudes that will be fixed on the next version of the program, to be implemented.

The neutronic component of ambient dose equivalent for the whole mission (both flights accumulated ambient equivalent dose) was measured by the CR39 PADC passive dosimeter, resulting in (4.10 ± 0.98) µSv. This value is in agreement with the one measured by active dosimeter FH40G-10 (5.03 ± 0.12) µSv for the whole mission, within 1 sigma confidence interval.

4. CONCLUSIONS

The experimental results show a good agreement, within the typical interval cited on reference literature. The differences between experimental results and computational estimates need to be further investigated.

It is important point out that the data presented in this paper are the first results of measurements made by Brazilian research group, with international collaborators. All these measurements are part of a wider effort from Brazilian Air Force to establish some knowledge and expertise in this area and investigate the possible influence of SAA on the dose received by aircrews and onboard instrumentation.

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