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Effects of Cosmic Radiation in Aircrafts: A Discussion about Aircrew over South America

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Abstract: *This paper has discussed the guidelines included in the documents of the International Commission on Radiological Protection (ICRP) on radiation protection applicable to aircraft and crew, and this is a brief report of the evolution of studies in this field of activity, as well as the regulations and recommendations already adopted by member countries of the European Union, Canada, and the United States of America. Some peculiarities of the Brazilian airspace and legislation applicable to the work with ionizing radiation are also presented, discussing the general aspects of radiological protection applicable to aircraft crew in Brazil.*

Keywords: *Aircrew, Radiation dose, Cosmic radiation, Aircraft.*

INTRODUCTION

With the increase in the number of commercial aircraft operations, in the recent decades, the act of controlling the level of ionizing radiation dose received by aircrew and sensitive equipment has received great attention from researchers, who motivated several studies in the international literature (FAA, 1990; Wilson *et al*., 1998; Bartlett, 2004; Hajek *et al*., 2004; Vergara and Román, 2009; Meier *et al*., 2009). The reason for this concern comes from the fact that the dose rate arising from the cosmic radiation (CR) in the atmosphere has increased considerably with altitude, so that aircrew of high operational ceiling can often exceed the annual limit dose proposed by international organizations for individuals of the public (ICRP, 1991; 2007), which is 1 mSv. The increase of the dose rate caused by CR and its subproducts generated in the atmosphere at various altitudes, calculated in the region of São José dos Campos in January 2008, is shown in Fig. 1 (Federico *et al*., 2010). For example, a crew member that fulfilled an annual workload of 600 hours of flight time in a typical altitude of 10 km, around this latitude, would receive an annual dose of 1.4 mSv.

The International Commission on Radiological Protection (ICRP) recognizes the need to control the exposure of the person representing the flight professional group, like pilots and crew, as this group is exposed to radiation levels that are comparable to the average levels of radiation received by professionals working with radiation in Medicine and Nuclear Technology (ICRP, 1998).

In Brazil, comprehensive studies on this subject were started in 2008 at the Institute of Advanced Studies, in the Department of Aerospace Science and Technology (IEAv/ DCTA) of the Air Force Command in São José dos Campos, in collaboration with researchers from two institutes of the National Commission of Nuclear Energy (CNEN): Institute of Nuclear and Energy Research (IPEN) and Institute of Radiation Protection and Dosimetry (IRD).

The purpose of this paper was to discuss the general aspects of radiation protection to be applied to crews of civil aircraft and military routes, which travel in high altitude in the light of international experience reported in the literature and international guidelines and standards.

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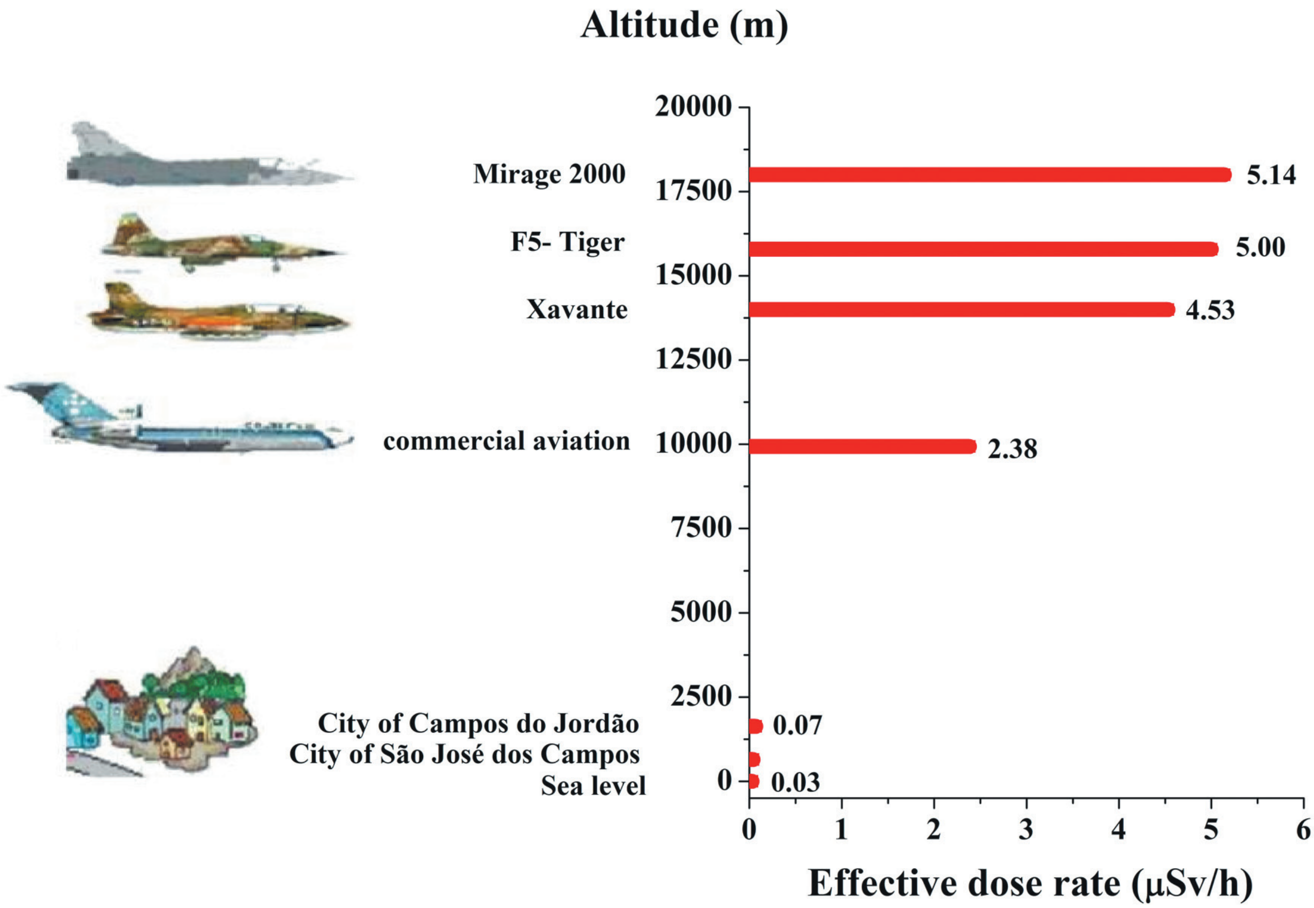

Figure 1. Illustration of the increased rate of effective dose as a function of the altitude calculated for January, in 2008, at the latitude of São José dos Campos.

THE STATE OF CREW WORLDWIDE

Except for nuclear material mines in operation, natural sources of radiation are usually excluded from radiological control, for they are considered outside the scope of radiation protection. However, in some cases, they may become a public health problem. The CR reaches all human beings on the Earth's surface and consists of a significant portion of the natural radiation dose to which everyone is exposed throughout their lives. But, as shown in Fig. 1, the dose rates can reach a hundred times higher values in flight altitudes and, therefore, depending on the time spent at this altitude, the dose accumulated by an individual may be greater than the one received by the population in general.

In 1990, the ICRP proposed in paragraph 136 of its report number 60 (ICRP, 1991) that pilots and crews, among others, should be considered as personnel occupationally exposed to ionizing radiation. In the same recommendation, it also warns about the possible need to control it for certain groups of professionals who make frequent trips, such as couriers. Along the same line of action, the European Union (EU) has adopted, since 1996, a new regulation to be applied by all member states of the European Community (Courades, 1999). The Policy 96/29/EURATOM of 13 May, in 1996 (EURATOM, 1996), in its article 42, establishes that the following measures should be taken in order to control exposures to crews that may be subject to annual doses exceeding 1 mSv:

- assess the exposure of the crew concerned;
- take into account the assessed exposure when organizing working schedules with a view to reducing the doses of highly exposed aircrew;
- inform to the workers concerned of the health risks their work involves;
- as soon as a pregnant woman informs the undertaking, in accordance with national legislation and/or practice, of her condition, the protection of the child to be born shall be

comparable with that provided for members of the public. Conditions for the pregnant woman in the context of her employment shall therefore be such that the equivalent dose to the child to be born will be as low as reasonably achievable, and it will be unlikely this dose will exceed 1 mSv during at least the remainder of the pregnancy.

As a result of such policy, considerations about this subject were incorporated to specific Operating Procedures JAR-OPS-1390 (JAA, 2001), from the Joint Aviation Authorities (JAA), an organization that brings together the European authorities in the field of aviation.

Currently, these guidelines are already followed routinely by EU member countries and companies based in those countries. Some companies even have already some of its fleet equipped with radiation monitors (Thierfeldt *et al*., 2009), which may serve to check the consistency of the measured dose with the estimates made by means of computer programs. A greater coordination between the dosimetric information obtained in each company or country has been investigated (Thierfeldt *et al*., 2009). The recommendation of the ICRP number 75, published in 1998 (ICRP, 1998), which deals with general principles of radiation protection of workers, clearly states, in its paragraph 164, that the exposure of aircraft crew members should be treated under the aegis of occupational exposure and it outlines some additional considerations:

- the annual effective doses should be derived from the flying time and typical effective-dose rates for the relevant routes;
- since there are no other practical control measures, there is no need to consider the use of designated areas;
- it is likely that the existing restrictions on the flying time of aircrew will provide sufficient control to exposures;
- pregnant members of aircrews are usually relieved of flying duties before the end of pregnancy.

These recommendations were later strengthened in the ICRP recommendation number 103 (ICRP, 2007), which maintain the same line of action. Consistent with the recommendations of the ICRP (ICRP, 1991; 1998) and the EURATOM Directive 96/29 (EURATOM, 1996), groups in Canada, in 1996, began studies on this subject, with the participation of the Royal Military College of Canada, which culminated in 2001 with the publication of the Commercial Recommendation and Business Aviation Advisory Circular 183 (TRANSPORT CANADA, 2001). This was subsequently revised and is currently in its version 183R, of April 28, 2006 (TRANSPORT CANADA, 2006).

The circular 183R follows, in general, recommendations for controlling crew doses proposed by the ICRP, establishing intervention levels for practice, and it proposes greater care in case of routes at high or polar latitudes, more susceptible to the effects of CR and possible solar flares.

Less rigorous, the Federation Aviation Administration (FAA), from the Department of Transportation, also manifested by issuing a series of recommendations on the subject, culminating in the Advisory Circular AC 120-61A (FAA, 2006). This recommendation discusses reference materials on the subject, the variables that influence exposure of crews, and provides guidance on the recommended limits and associated risks, recommendations on the management of exposures of the crew and computer codes to be used for the estimation of doses among other information.

PREGNANT CREW

From the point of view of radiological protection, an often important factor in most of the existing guidelines on the subject, is the large proportion of young females in aircraft crews (Alves and Mairos, 2007; Beck *et al*., 2006), a feature which may involve a higher risk for hereditary effects of radiation introduced into the population. This, thus, requires procedures to protect the fetus, in the case of pregnant women occupationally exposed to ionizing radiation of cosmic origin.

Under the aspect of quantification of the dose to the fetus, it should be noticed that for individuals exposed to CR, studies show that, given its high penetration capability, the dose at the surface of the mother's abdomen is approximately the same one to the fetus (Courades, 1999; FAA, 2000). Due to the high radiosensitivity of the fetus, the dose limit proposed by ICRP (1991) for the fetus is 1 mSv during the remaining period after the pregnancy confirmation.

As pregnant women crew are usually separated in flight activity well before the end of pregnancy, the ICRP 75 (1998) considers, in its paragraph 164, that there are no necessary restrictive additional measures, and that the proper control of doses already received allows the prevention of exceeding the dose limit in the fetus. Thus, one should emphasize the importance of an adequate control of their doses, also considering the possibility of anomalous effects arising from flights during solar and magnetospheric disturbances, where the dose rates may increase or decrease significantly for short time, reaching the units of mSv per hour (Lewis *et al*., 2009).

DOSIMETRIC CONTROLS

Due to its characteristics of reasonable predictability, and the fact that a particular flight crew is subject to the same radiation dose, the ICRP does not recommend, nor considers necessary, to carry out individual monitoring of the dose by the crew of personal dosimeters. The estimation of doses received by crew can be effected by means of computer codes, which are based on data from the flights made, such as route, altitude, time travel, and geophysical parameters (solar wind and magnetospheric disturbance index).

The international community attaches great importance to these controls, so that there are several, free or commercial computer codes, which allow the calculation of radiation dose on several routes. These codes perform the estimates of doses based on simulations of the interaction of primary CR in the atmosphere by Monte Carlo method, or on analytical solutions of the transport equation of particles in the atmosphere, or through adjustment of empirical functions to the existing experimental data. A description of the commonly used codes can be found in Botollier-Depois *et al*. (2009). Some of these codes were tested and their results were compared with measurements made on board of aircraft in some routes and points of the national territory (Federico, 2011), and there is reasonable agreement between calculation and measurement, with the uncertainty around 12% (1 sigma).

Based on estimates obtained from such computer codes, one can make an appropriate crew dosimetric control. To ensure the reliability of dose estimates obtained computationally, computational estimates should be checked regularly by means of direct measurements of the doses received in flight. The measurement quantity to be used for radiological protection purposes is called effective dose (E), measured in the unit called the Sievert (Sv), which allows an immediate comparison of its value with the limits proposed by the regulatory bodies. However, for operational purposes, some computer codes, as well as most of the measuring equipment, are calibrated in the measurement quantity known as ambient equivalent dose (H*(10)), which can be considered a reasonable estimate for the E, where they meet the qualifications presented in ICRP recommendation number 103 (ICRP, 2007) and ICRU report number 84 (ICRU, 2010).

DOSES IN BRAZILIAN AIRSPACE

In recent years, many measurements have been carried out, and experimental studies of the routes of the Northern hemisphere, covering flight altitudes between 8 and 20 km and latitudes 30°S to 70ºN (Sullivan *et al*., 2002; Bartlett, 2004; Vukovic' *et al*., 2010). Sullivan *et al*. (2002) reported dose rates ranging from 1 to 17 μSv/h. However, few studies have been conducted in South America, and of these few, most of them evaluates the information of the route that begins in South America, but ends in the northern hemisphere, or vice versa, and reports the result as a whole, not detailing the behavior of the dose rate in South America.

An important factor to be considered for the region of South America is the presence of a magnetic anomaly, called the South Atlantic Magnetic Anomaly (AMAS), which covers most of the Brazilian territory. It is a region where the magnetic field lines approach the Earth crust, and can modify the form of development of CR secondary shower in the atmosphere. Figure 2 shows the mapping in the form of contour lines of the Earth's magnetic field at an altitude of 12 km, obtained through the model geomagnetic International Geomagnetic Reference Field (IGRF2011), where one can see that the region has the lowest intensities of the planet's magnetic field. Another issue is about the potential enhanced particle precipitation over this region, compared to others in the world, due to seasonal variations on solar activity as due to sporadic sudden solar flares. Worth is noting that the Earth's magnetic field acts as a protective shield for CR, trapping and deflecting the particles incident on earth (Heinrich *et al*., 1999).

Some studies have been developed on AMAS since 1968 using stratospheric balloons and other methods (Martin, 1972; Costa, 1981; Pinto Junior, 1985). Most of them indicate that AMAS modifies the incident radiation at high altitudes, but sensitive modifications were not detected at lower altitudes, consistent with the commercial aviation altitudes. However, it is important to note that these studies have focused on space geophysics purposes and not for the purpose of measuring dose in crew, and the quantities used and energy ranges relevant to these studies are different from those applied in ionizing radiation dosimetry. Moreover, at these altitudes, the contribution of neutrons can reach up to 40% of the total dose; the distribution of energy is important, as the dose associated with neutrons is strongly dependent on its energy.

The standard radiation protection of the Brazilian Commission of Nuclear Energy (CNEN) NN-3.01 (CNEN, 2005) considers an individual as one occupationally exposed (IOE) to radiation when it is subjected to normal and potential exposures (associated with accidents and unforeseen situations), as a result of their work or training in permitted practices or interventions, excluding natural radiation of the site. In this same standard, the term "Natural Sources" as sources of naturally occurring radiation, including CR and terrestrial; in the absence of Standard CNEN-NN 3.01, there are no reservations in relation to the case of aircraft crews, which are subject to the exposure of CR due to their work activities.

However, dose calculations made based on actual data for airflow, recorded by airspace control centers at altitudes of 29.000 to 41.000 feet, through the code CARI-6 (EURADOS, 2004) and compared with the statistics of Brazilian crew workload, show that a typical Brazilian aviation company aeronaut who, by definition, has a main routine flight travel in Latin America and the Caribbean, should receive average annual doses around 1.4 to 1.6 mSv, exceeding therefore the public individual dose limit (Federico, 2011).

CONCLUSIONS

As reported in this work, it can be seen that since 1990 the concern for crew radiation protection has been the subject of studies and discussions at the international scientific environment, and the object of attention of international standards setting organizations. In the EU and in Canada, aircrew is recognized as people occupationally exposed to ionizing radiation, and some guidelines were established to control exposure. According to these guidelines, crew with the possibility of being exposed to doses above 1 mSv per year have their doses controlled. Likewise, the U.S. recommendations in this regard have been issued.

However, the Brazilian standard, CNEN – NN 3.01, does not provide clear mechanisms for considering aircraft crew as occupationally exposed to ionizing radiation, although this crew may be subject to comparable doses to radiation workers in the medical field or industry. Until now, the Brazilian regulatory authorities in the field of aviation and health considerations have not yet issued anything regarding to this subject.

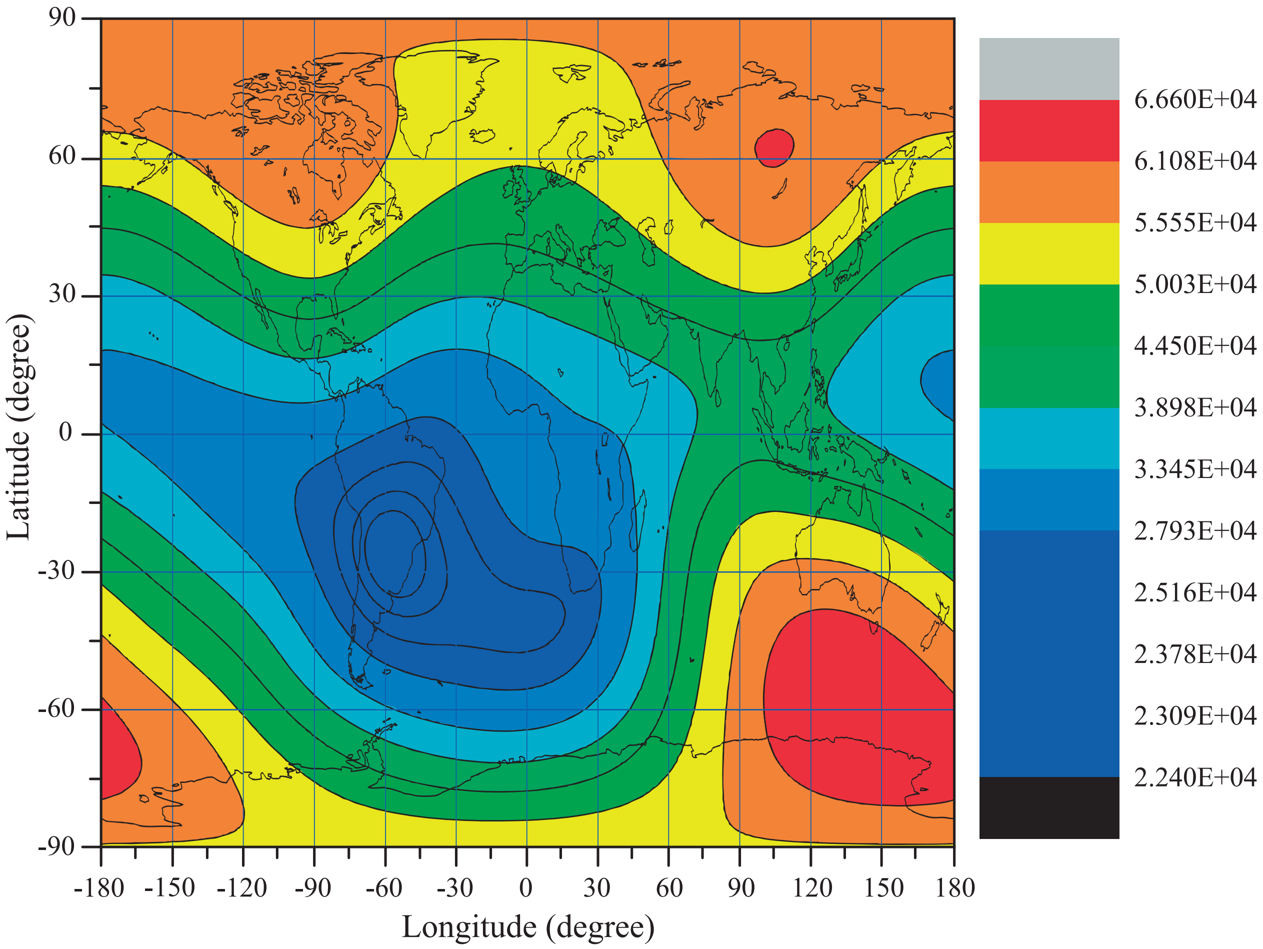

Figure 2. Map of the magnetic field (total intensity, expressed in nT) obtained by the model IGRF2011 for October 1st, 2010.

Data derived from actual measurements and scientifically based studies are of fundamental importance to objective and well-founded evaluation on the impact in occupational health of aircrew flying high ceiling and its impact in this group and the effects on public health (population). Brazil, like the European Union, Canada and the United States, but mainly as a result of its peculiarities, should develop the capacity to carry out radiation measurements in aircraft and to assess the risk to crew and sensitive instrumentation; otherwise, it would remain dependent on conclusions based on measurements taken by foreigners outside AMAS.

Therefore, this research is expected to provide to normalizing authorities and legislators concrete and realistic data about the effects of CR in the Brazilian airspace. Also, it should provide assessment tools so that they can mark the establishment of rules for protecting health, avoiding that, for the sake of protection, overly restrictive measures are taken, or not, because of lack of assessment of the subject with a scientific basis. Finally, the impacts on the economy arising from the airlines should be taken into account to consider the IOE crew as exposed to ionizing radiation, without, however, failing to evaluate the cost-effectiveness for the individual and society control to the exposure of crew to CR.

The Brazilian labor law stipulates financial compensation as well as special retirement and differential vacation for workers occupationally exposed to ionizing radiation. The condition of occupational exposure, even within the limits established by CNEN, is associated with the condition of danger, taking into account the long-term stochastic effects of radiation on the organism and the potential exposure due to accidents and unforeseen situations. However, for exposure to cosmic radiation, crew accumulated annual doses are within regulatory limits, and there is no possibility of accidental exposures, since the CR varies within a known range of values (maximum and solar minimum), except in the rare solar events of great magnitude, which affects the population as a whole.

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