A SIMPLE METHOD FOR ESTIMATING COSMIC RADIATION DOSES FOR AIRCREW

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Abstract

In Turkey, about 15,000 people are employed as aircrew. In this study, the effective dose of the aircrew due to cosmic radiation has been proposed a simple method for estimating radiation dose. In this article, using CARI-6 program can run a new program has been prepared in EXCEL on the PC based Windows operating system. Using this program, various altitudes, latitude and longitude cosmic radiation dose rates were calculated. The results calculated using a simple method in comparison with the original CARI-6 calculated at several flight data flight doses has been found to be compatible. Using this method for 0 to 20,000 m in altitude cosmic radiation doses can be calculated without the need for another program.

Keywords: Cosmic Radiation, Dose, Aircrew, CARI-6, EXCEL

Introduction

In Turkey, about 15,000 people are employed as aircrew [1]. The European directive EURATOM 2013/59 the safety standards for protecting the health of the population and workers from the dangers arising from ionizing radiation publication is the extension to cover exposure to natural radiation. Article 35 makes the following provisions for the protection of flight crews:

"Each Member State shall make arrangements for undertakings operating aircraft to take account of exposure to cosmic radiation of air crew who are liable to be subject to exposure to more than 1 mSv per year. The undertakings shall take appropriate measures, in particular:

- to assess the exposure of the crew concerned;
- to take into account the assessed exposure when organizing working schedules, with a view to reducing the doses of highly exposed aircrew;
- to inform the workers concerned of the health risks their work involves;
- to apply Article 10 to female air crew."

Article 10 of the directive makes special provisions for protection during pregnancy. As soon as a nursing woman informs the undertaking of her condition she shall not be employed on airborne duties if the equivalent dose received by the unborn child is likely to exceed 1 mSv [2]. Directorate General of Civil Aviation will adapt this directive to Turkish regulation in 2014 [3].

Cosmic radiation has two components, one stable and of galactic origin, the other more sporadic and associated with solar activity. The stable component of cosmic radiation has its origins in the galaxy. It is made up of highly charged particles ejected by the gigantic explosions of supernovae, massive stars which have reached the end of their lives. These particles are atoms that have been stripped of their electrons because of the prevailing temperatures within these giant stars. They are of different types, mainly with hydrogen nuclei (protons) and helium nuclei (alpha particles), but also with far heavier nuclei such as iron and nickel. They travel close to the speed of light.

On the whole, galactic cosmic radiation is isotropic, which means that it is the same in all directions. As a result, the entire surface of the Earth is constantly exposed to it.

Table 1. Composition of galactic radiation

Composition of galactic radiation	Level
Particles Level hydrogen nuclei (protons)	85%
Helium nuclei (alpha particles)	12.5%
Nuclei made of heavier atom	1%
Electrons	1.5%

A proportion of galactic radiation is diverted by the Earth's magnetic field, which is distorted by solar wind. In effect, the suns atmosphere constantly releases a particle flux that fills interplanetary space, which we refer to as the solar wind. The characteristics of the solar wind, particularly the magnetic ones, vary depending on solar activity and create a field that deflects cosmic radiation from the Earth. In this way, galactic cosmic radiation reaching the Earth is reduced during periods of high solar activity. As we know that, on average, solar activity follows an 11-year cycle, it is possible to predict average exposure to galactic radiation over a number of years Figure 1[4].

Figure 1. Variation of cosmic radiation and solar activity.

The sun is the source of the sporadic component of cosmic radiation. The sun constantly ejects particles with an intensity that varies according to an 11-year cycle. These particles add to galactic radiation, however, having less energy than those originating from the galaxy, only a small proportion of them reach the Earth.

In fact, the suns main contribution to the exposure of people on board aircraft results from unpredictable solar flares. Major solar flares release large quantities of particles for several hours. Nevertheless, only flares generating a particle flux that have a sufficiently high energy are detectable on the ground or on board aircraft and these flares are rare, with only a few occurring a year at the most.

These flares are more abundant during periods of maximum solar activity, as in 2012-2013. At such times, the suns magnetic field is particularly disturbed, which results in the appearance of a large number of sunspots on its surface. Large solar flares emerge from the most complex groups of sunspots. Although they are more frequent at the peak of the solar cycle, solar flares can nevertheless occur at any time.

Unlike stable galactic radiation, the particles resulting from solar flares are not distributed evenly across the surface of the Earth. In order to determine their impact, it is necessary to measure their intensity and undertake scientific calculations on a case by case basis.

Before reaching the ground or an aircraft's cruising altitude, cosmic radiation is partially blocked by two "barriers" protecting the Earth: the planet's magnetic field (which creates a region isolated from solar wind known as the "magnetosphere") and the Earth's atmosphere. It is this dual protection that enabled life to develop.

Table 2. Two components of galactic cosmic rays

Cosmic rays	Solar particles
permanent	sporadic
high energy particles 100 MeV -1 GeV	medium-energy particles <100 MeV
Max energy 10^{20} eV	Max energy 10 GeV
isotropic	anisotropic

Particles that finally reach the ground contribute to human exposure to ambient ionizing radiation of which they only represent a small proportion (the other source of radiation is the Earth itself). However, their relative proportion increases rapidly at altitude (mountains, aircraft, spacecraft, etc.).

Like all electrically charged particles, the ions that make up cosmic radiation are channeled or diverted by magnetic fields, like the needle of a compass, for instance. The Earth can be viewed as a huge magnet surrounded by a magnetic field, with force lines that "enter" by the North Pole and "exit" by the South Pole: this is what is known as the magnetosphere [4].

If the cosmic particles possess energy that is above a certain threshold, known as magnetic cut-off energy, they pass through the magnetosphere and reach the upper layers of the atmosphere. However, if their energy is not sufficient, they will tend to follow the magnetic field's force lines, with greater "ease" since they have less energy, and thereby reach the poles. This is why the areas near the poles are exposed to a greater particle flux than the areas at the equator, which are better protected by the Earth's magnetic field. Figure 2.

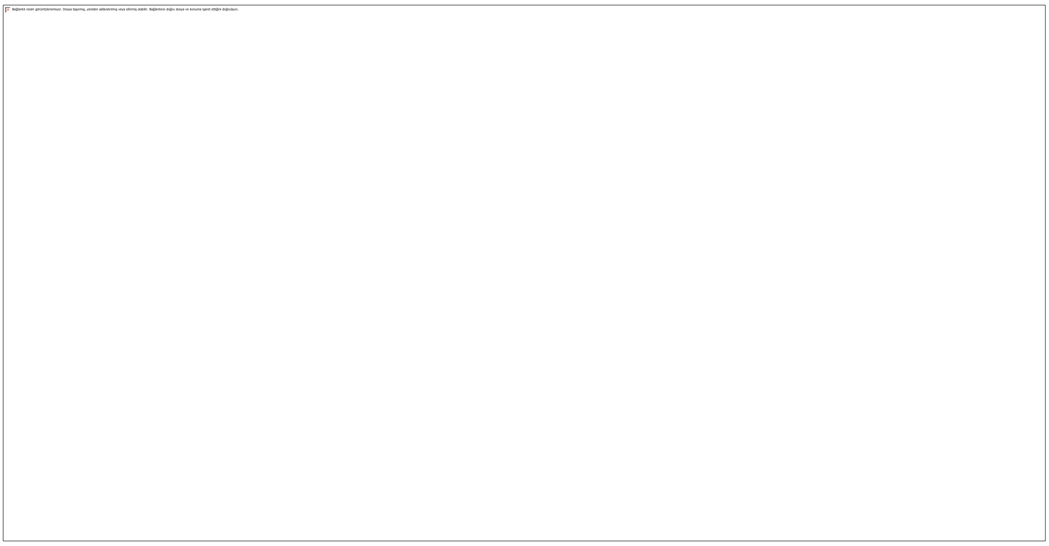

Figure 2.Illustration of the magnetosphere, which protects the Earth from the effects of solar wind.

As they reach the upper layers of the Earth's atmosphere, ions interact with the atoms they encounter. These collisions result in showers of new particles. It is this secondary radiation, consisting specifically of charged particles and neutrons, which is able to reach the ground, at least when the primary particle has sufficient energy [5].

Material and Method

The CARI-6 computer program calculates the effective dose of galactic cosmic radiation received by air travelers on flight data between origin and destination airports. CARI-6 software runs under DOS operating system. Since avoiding DOS, a simple macro code is prepared under EXCEL Spread sheet.

Table 3 . CARI-6 Parameters

Parameter	Minimum	Maximum	Increment
MV*	0	2000	100
Latitudes	-90º	90º	10º
Longitudes	-180º	180º	10º
Altitudes (ft.)	0	60’000	1’000

(*) MV= Heliocentric potentials

Firstly, CARI-6 software runs with parameters are given in Table 3. Data are taken from CARI-6 put into 20 different EXCEL Sheets. Each Sheet keeps 46361 data. In this study, four flights are chosen from Istanbul. These flights are to Helsinki, New York and Johannesburg sketched in Figure 3. Flight data are taken (flight date-MV’s, latitude’s, longitude’s and flight altitude’s) from internet [6]. Effective doses are calculated by using CARI-6 and flight data. Then, effective doses are found by using same flight data and EXCEL sheets too. The results are tabulated in Table 4 with SIEVERT SYSTEM [7].

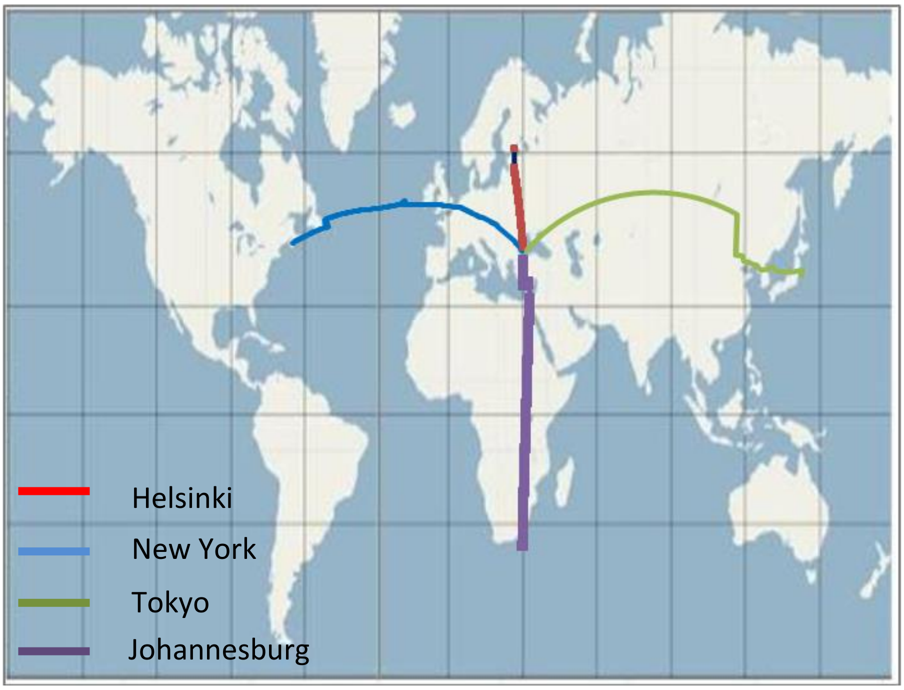

Figure 3. Four flights from Istanbul.

Conclusions

Several programs are now available for route dose calculation, such as CARI-6, EPCARD, SIEVERT and PCAIRE. The characteristics of these models including properties of other models and services are well explained in a report by the European Radiation Dosimetry Group [8].

Tablo4. Effective doses

Flight (from Istanbul)	Flight Time (hh:mm)	CARI	EXCEL	SIEVERT	Difference (%)
Helsinki	2:40	7.0	7.1	9.8	1.43
New York	10:19	55.9	57.0	56.9	1.97
Tokyo	11:14	43.3	46.3	52.0	6.93
Johannesburg	9:03	22.3	22.1	18.7	-0,90

Flight date: 1/6/2014.

From EXCEL data it possible to calculate uncertainty as the description in ISO-GUM [9]. Due to uncertainty of all these data represented by a rectangular distribution, sum of all uncertainties is defined as

$$u_c = \sqrt{(u_{MV})^2 \; + u(u_{la})^2 + (u_{lo})^2 u + (u_{al})^2} \qquad \{E.1\}$$

where u_c: combined uncertainty, u_{la}: uncertainty of latitude, u_{lo}: uncertainty of longitude and u_{al}: uncertainty of attitude. Over all uncertainty is 15.2 % in effective dos rate. The most uncertainty comes from MV (Heliocentric potential). In total effective dose error is less than the calculated uncertainty for our flights as seen in Table 4.

Table 5. Uncertainty

Parameter	Uncertainty %
MV	14.3
Latitudes	1.8
Longitudes	6.6
Altitudes (ft.)	2,2
Total uncertainty	15.2

It is advised to prepare a particular software like CARI-6, SIEVERT codes etc. for several airline companies in Turkey. This software may be based one of FLUKA, LUIN, PLANETOCOSMIC (ROOT, GEANT4) [8].

Reference

1. http://www.turkishairlines.com/tr-tr/kurumsal/kariyer/calisan-profili
2. European-Council Directive 2013/59/EURATOM laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (5 Dec 2013).
3. Personnel conversation with Mr.Fırat Davut, Turkish Airlines Expert, May 2014.
4. UNSCEAR 2008 Report. United Nations, New York, 2010
5. Journal of the ICRU Vol. 10 No 2 (2010) Report 84, Oxford University Press.
6. www.flightaware.com , 13/7/2014 access.
7. www.sievert-system.org , 13/7/2014 access.
8. Cosmic Radiation Exposure of Aircraft Crew, Radiation Protection 140 Publication, EUROPEAN COMMISSION, 2004.
9. Guide to the expression of uncertainty in measurement (GUM), ISO/IEC Guide 98-3:2008.