MEASUREMENT OF COSMIC RADIATION EXPOSURE OF AIRCRAFT CREW AT COMMERCIAL AVIATION ALTITUDES

by

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The measurement results of ambient dose equivalent rate in an aircraft, performed by a standard portable dosimeter, at a non-commercial flight Belgrade – Podgorica at altitudes up to 9000 meters, are shown. By numerical interpolation of the measurement results, a functional dependency of the ambient dose equivalent rate on the altitude of the airplane flight is determined, obtaining a good agreement with the reference values. For commercial airlines in the Balkan region, total ambient dose equivalent, regarding the aircraft crew occupationally exposed to radiation in the course of a flight, was calculated and the maximum permitted number of flight hours per year, was estimated.

Key words: cosmic radiation, ambient dose equivalent rate, portable dosimeter, aircraft crew, Balcan region

INTRODUCTION

The aircraft crew and the passengers are exposed to high levels of radiation emitted from the sun and cosmic deep space, wherein the exposure to cosmic radiation approximately doubles for every 2000 meters of raising the flight altitude [1]. This exposure does not pose almost any health risk to an average air traffic passenger, travelling occasionally, but the health of the airplane crew and even business people may be affected depending on the altitude and the amount of time spent on flight. Hence, in 1991, the International Commission on Radiation Protection recommends that exposure to cosmic radiation of aircraft crews on commercial flights should be regarded as occupational exposure [2], which is supported by subsequent publications on this subject [3, 4]. Also, the time of flight control measures and route selection regarding a crew, were proposed.

At altitudes of commercial airline flights, cosmic rays in the air originate, to the greatest extent, from proton and alpha particles coming from beyond the solar system which, on entering the earth's atmosphere, successively collide mainly with the atoms of nitrogen and oxygen, producing photons and other subatomic particles. The Earth's magnetic field provides partial protection from cosmic radiation – the protection is strongest at the equator and weakest at the poles. The reason for this is the direction of incoming cosmic radiation in relation to the direction of the Earth's magnetic field. At the equator, the direction of cosmic radiation movement is perpendicular relative to the direction of magnetic field lines, while at the poles, the angles between these lines are lesser [5]. Moreover, the level of cosmic radiation at a geographical position is never constant. Long-term studies have demonstrated that there are solar cycles of about eleven years of solar activity that affect the intensity of cosmic radiation in the Earth's atmosphere. In addition, solar storms (mainly emission of protons and electrons) can happen at any time, but more often occur during the peak of the solar cycle. As the cosmic radiation consists of charged, ionized particles, they are under the influence of highly ionized particles from a solar storm. Perturbations in the Earth's magnetic field, caused by solar storms, scatter low-energy particles of cosmic radiation that would otherwise have entered the Earth's atmosphere. For this reason, the intensity of cosmic radiation is at a minimum during solar maxima.

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Studies of the characteristics of cosmic radiation in the Earth's atmosphere and its impact on the human population were extensively carried out in the world, both theoretically and experimentally [6-10]. Recently, measurements of the cosmic ray dose rate and evaluation of health risks for aircraft personnel in civil air transport of the former Yugoslavia, was done [11, 12]. This paper presents the measurement results of ambient dose equivalent rate, obtained by a standard portable dosimeter 6156AD6, on the flight Belgrade to Podgorica and back, derivation of a simple exponential function of dose rate dependence on the flight altitude and estimation of exposure of the crew and passengers in an aircraft on regional lines in the Balkans.

PROCEDURE AND CONDITIONS OF MEASUREMENT

Measurement of the ambient dose equivalent rate ($H^*(10)$) due to cosmic radiation was carried out on 2 and 3 February 2015 on flights Belgrade – Podgorica and Podgorica – Belgrade. A plane Hawker Beechcraft King Air 350, made in USA, the property of the Serbia and Montenegro Air Traffic Services (SMATSA) was used. This plane SMATSA benefits for calibration of radio-navigation aids and checking of published flight procedures. While measuring the cosmic radiation dose rate, the instruments on the plane did not have any impact on the dosimeter operation. Due to the nature of the service for calibration work, flights that were carried out lasted a lot longer than the commercial flights on these routes.

In order to perform measurements a portable dosimeter 6150AD6 was used, product of Automess firm (Automation und Messtechnik GmbH) [13], which is calibrated in the Secondary Standard Dosimetry Laboratory (SSDL) of Department of Radiation and Environmental Protection of the Vinča Institute of Nuclear Sciences. This device has a built-in Geiger-Miller's counter, displays the cumulative dose and the dose rate in analogue and digital form. In digital mode, the dosimeter is measuring the ambient dose equivalent rate in the range from 10 $nSvh^{-1}$ to 99.9 $mSvh^{-1}$ and in the energy range from 60 keV to 1.3 MeV, with declared deviation referred to Cs-137 of maximum 30%.

Clock and altimeter that were used during the measurement were a part of the AD-AFIS-260 system manufactured by Aerodata AG. Accuracy of the clock is a hundredth of a second, while the accuracy of the altimeter is 10 feet, or about 3 meters.

The cities are located in temperate northern latitudes: Belgrade at 44°49'14" and Podgorica at 42°26'27", with a difference of nearly 2.5 degrees. It is believed that this change of latitudes affects the change of cosmic radiation dose rate in the range of 3 % [6], while longitudes of the cities are not essential.

At the time of measurement, the state of the solar cycle was at the beginning of the transition from solar maximum to minimum [1]. As during the solar maximum cosmic radiation is less than during the solar minimum, it can be assumed that the radiation during the measurement was less than it will be in the years to come.

Since the flight was conducted in order to investigate the radio-navigation aids, as well as the flight test procedures, the altitudes deviated from the usual altitudes of civilian flights. When going to Podgorica, the plane was cruising at an altitude of 9000 meters, while in return the height varied. Common commercial flights, on these routes, in one direction, last less than an hour, while the flights during which the measurement was carried lasted more than two hours each.

RESULTS OF MEASUREMENTS

The ambient dose equivalentrate measurements were carried out over two flights in two days, whereby the first flight from Belgrade to Podgorica provided more detailed and reliable results.

The flight route Belgrade – Podgorica

Figure 1 shows the altitude of the flight on the route Belgrade – Podgorica, depending on the duration of the flight. At zero minutes, that is, at the beginning of the measurement, the plane was at an altitude of 90 meters. The climbing phase of the aircraft lasted 16 minutes and during that time the airplane has reached a height of 9000 meters.

At the 16th minute, the aircraft starts the cruise phase maintaining constant altitude of 9000 meters. At the 36th minute, the calibration of terrestrial devices and flight procedures started and measuring the radiation dose rate was not done. This was shown as a bro-

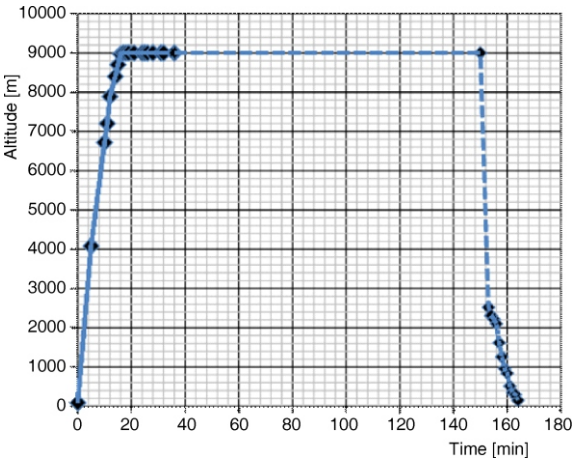

Figure 1. Dependence of aircraft altitude on the flight time

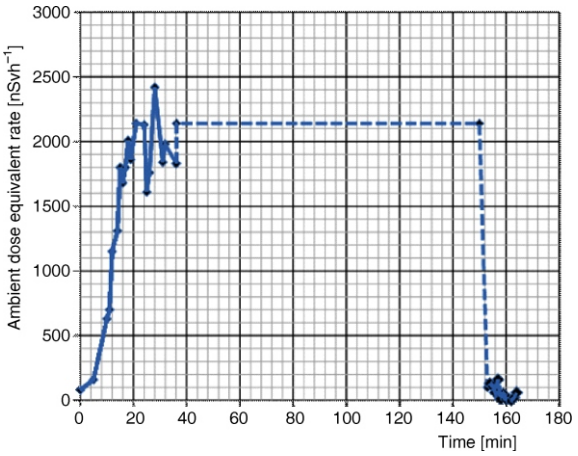

Figure 2. Ambient dose equivalent rate due to cosmic radiation as function of the time measured on the flight

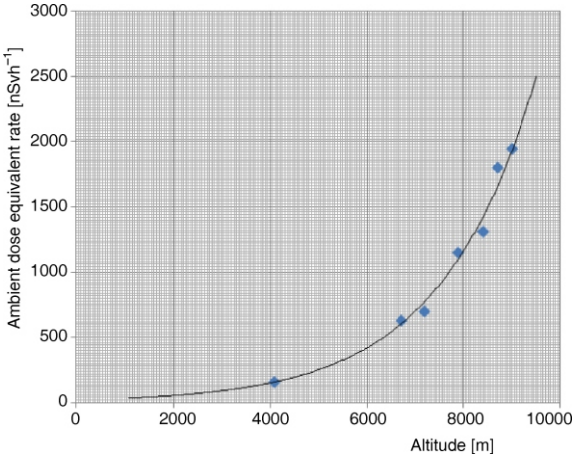

Figure 3. Ambient dose equivalent rate due to cosmic radiation as function of the altitude measured on the flight

ken line in fig. 1, characterizing the period in which the measurements were not performed.

Measurement was continued in the 153th minute of flight, when the plane was at an altitude of 2520 meters. From that moment onwards, the aircraft descended and landed at Podgorica airport.

Scheduled flights on the route Belgrade – Podgorica, are lasting from 40 minutes to an hour, depending on the type of aircraft. This flight, due to its specific purpose, lasted over two and a half hours.

The ambient dose equivalent rate as function of the time measured on the flight on the route Belgrade - Podgorica is shown in fig. 2. At the moment of switching the dosimeter on, at a height of 90 meters, the ambient dose equivalent rate was 80 nSvh^{-1}. As the airplane was climbing to cruising altitude of 9000 meters, the dose rate of radiation also rose. While flying height increased with time almost uniformly, the dose rate was registered with substantial variations. These variations can be attributed to flight conditions, characteristics of the dosimeter and altimeter. Every two seconds the dosimeter had shown a new value and there was a delay in response to the change of external radiation. Aircraft altimeter works by measuring changes in the atmospheric pressure, which is recorded directly by Pitot tubes housed on the fuselage. Altimeter gives response without delay, mechanism of the device responds to the slightest pressure change, at any time, by giving a precise value.

After reaching an altitude of 9000 meters, or at 16th minute of flight, cruising phase of the plane flight began, that was recorded to 36th minute. During the cruise phase, oscillations in the intensity of cosmic radiation dose rate were registered, due to turbulence of the flight, varying of atmospheric conditions and imperfections of the dosimeter. Based on the measurements, the mean value of the ambient dose equivalent rate was determined to be 1940 nSvh^{-1} at a height of 9000 m.

In fig. 3, the ambient dose equivalent rate as function of the altitude, measured on the flight, is presented. It turned out that the exponential function is in the form

$$H^*(10)(h) \quad 19.77\mathrm{e}^{0.51h} \tag{1}$$

where $H^*(10)$ is the ambient dose equivalent rate measured in nSvh^{-1} and h – the flight altitude, measured in kilometres. The expression (1) shows very good fitting of the values obtained by measurements. However, it should be noted that due to changes in the geographic co-ordinates of the aircraft position in the course of the flight, a single value of altitude may correspond to more measured values of cosmic radiation dose rate – as a result of changes in latitude, the stochastic nature of cosmic rays and other specifics of the flight and measurement techniques (meteorological conditions and measurement uncertainty).

In tab. 1 the values of the ambient dose equivalent rate, calculated using the expression (1), were compared to the reference values from literature, relating to 43° latitude and extreme activity solar cycle [6]. As the measurements were performed during the period of the solar cycle nearer to the solar maximum, the results obtained by the expression (1) have values that are close to the reference for solar maximum. Relative deviations from the referent values for solar maximum are less than 9 % for an altitude of 9 000 meters and amount to 19 % for 4000 meters. It should be borne in mind that the measurements are carried out inside the cabin of the aircraft, and the obtained results are lower than the reference relating to the free atmosphere.

Table 1. Dosimetric profile in the earth`s atmosphere

Altitude [km]	Ambient dose equivalent rate [nSvh^{-1}]		
	Solar minimum [6]	Solar maximum [6]	Our result, eq. (1)
4	202	187	152
5	313	289	253
6	503	463	422
7	796	730	702
8	1320	1200	1169
9	1970	1790	1947

Measurements on the flight Podgorica – Belgrade

In accordance with the need of calibration of the terrestrial navigation equipment and checking of the published flight procedures, the flight took place at altitudes lower than those on the flight Belgrade – Podgorica. The plane initially climbed to a height of 3000 meters, where it stayed for 8 minutes, after which it went diving to a depth of 1620 meters, because of that, the measurement of radiation dose rate was interrupted. At 162th minute of flight the measurement briefly continued at an altitude of 4500 meters, just before the descent and landing of the aircraft to the airport in Belgrade. These circumstances of the flight have prevented a reliable measurement of radiation dose rate and the recorded values are not shown here.

ASSESSMENT OF TOTAL RADIATION DOSES ON REGIONAL ROUTES

On the basis of the measured dose rate on the route Belgrade – Podgorica, one can calculate the total ambient dose equivalent of the exposure of the crews exposed during the regional flights in the Balkans. Regional flights are selected because they belong to an approximate latitudes, thus it can be considered that there is no significant influence of latitude on the dose rate. Regional carriers have different types of aircraft, some of which (ATR-72) are flying at altitudes up to 5500 meters, and the other (aircraft Airbus, Boeing, Fokker, Embraer) at altitudes up to 9000 meters. The assumption has been made that the flights take place at a height of 9000 meters, and from the moment of take-off the plane is immediately at this altitude, which will overestimate cosmic radiation impact on the crew, which is in favour of better protection of the crew.

Table 2 shows the total ambient dose equivalent to which the crew and passengers are exposed, in a single flight, in some regional airline routes. It is evident that for the flight Belgrade – Zagreb, the longest of the four, the maximum value of the integral dose due to cosmic radiation does not exceed 1558 nSv.

The need planning of aircraft crew exposure to the cosmic radiation

To reach the annual radiation exposure limit of 1 mSv (ICRP recommendations [2]) the crew should spend about 600-800 hours at an altitude of 9000 meters.Since airlines maintain flights to other countries, to which, in some cases, more hours of flight are required at altitudes higher than 9000 meters, the ICRP recommendations can certainly be exceeded. Hence, it is customary to perform measurements and analysis for the crew and the route on which a certain airline has flights [14, 15].

Bearing in mind that in the future, the need for air traffic will be increasing and that would raise the number of flights at the global level, as well as the number of hours that flight crew spend in the air, it is necessary to find solutions that will reduce exposure of flight staff to cosmic radiation. This can be achieved in the form of planning lower flight altitudes, or altered routes in terms of latitude, which is less likely and too expensive, while it is more probable that the flight schedule within the airline will be implemented according to the principles of strategic planning [16], which will enable even load of crews and minimal exposure to radiation.

Table 2. Total ambient dose equivalents on commercial flights in the area of the Balkans

Route of flight	Flight duration [h]	Ambient equivalent dose [nSv]
Belgrade – Zagreb	0.8	1558
Belgrade – Podgorica	0.7	1363
Belgrade – Skopje	0.76	1480
Belgrade – Sofia	0.6	1168

CONCLUSION

Measurements of the ambient dose equivalent rate due to cosmic radiation carried out in real conditions of flight, showed that commercial dosimeter can give reliable and satisfactory results. Based on those results, a simple exponential analytical function is determined, that gives dependence of ambient dose equivalent rate on the altitude of the aircraft. The calculated dose rates, according to the expression (1), show a good agreement with the known theoretical and experimental results, relating to the latitude corresponding to the Balkans and the corresponding period of the solar cycle. Finally, the single-flight ambient dose equivalent of radiation exposure of crew flying on commercial lines in the Balkan region, were estimated.

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AUTHORS' CONTRIBUTIONS

The measurements were carried out by V. M. Vujičić and data were evaluated and interpreted by V. M. Vujičić and D. R. Simović. All authors analysed the results and participated in writing the manuscript.

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МЕРЕЊЕ ИЗЛАГАЊА КОСМИЧКОМ ЗРАЧЕЊУ ПОСАДА ВАЗДУХОПЛОВА НА КОМЕРЦИЈАЛНИМ ЛЕТОВИМА

Приказани су резултати мерења јачине амбијенталног дозног еквивалента у ваздухоплову, обављеног стандардним портабл дозиметром на некомерцијалном лету Београд – Подгорица, на висинама до 9000 метара. Нумеричком интерполацијом резултата мерења одређена је функција зависности јачине амбијенталног дозног еквивалента од висине лета авиона и добијено је задовољавајуће слагање са референтним резултатима. За комерцијалне авионске линије у балканском региону израчунате су тоталне дозе којима су изложене посаде ваздухоплова у току једног лета и процењен допуштен број часова налета посаде у току једне године.

Кључне речи: космичко зрачење, јачина амбијенталног дозног еквивалента, преносиви дозиметар, посада ваздухоплова, Балкан