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EVALUATION OF EXPOSURE TO COSMIC RADIATION OF FLIGHT CREWS OF LITHUANIAN AIRLINES

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Abstract
Background. In Lithuania the average annual effective dose due to cosmic radiation at the sea level is 0.38 mSv. The dose rate caused by cosmic radiation increases with altitude due to the decrease in attenuation of cosmic radiation by atmosphere. Dose rates at altitudes of commercial flights are tens times higher than those at the sea level. For this reason people who frequently fly receive higher doses which might even be subject to legal regulations. The European Council Directive (96/29/Euratom) on basic radiation safety standards requires that doses of aircrews members be assessed and the appropriate measures taken, depending on the assessment results. **Objectives.** The aim of this study was to evaluate potential doses, which can be received by members of aircrews of Lithuanian Airlines. The assessment was done by performing measurements and calculations. **Methods.** Measurements were performed in flying aircrafts by thermoluminescent detectors, Geiger Muller counters and neutron rem counter. Such an approach lead to evaluation of doses due to directly ionizing particles and neutrons. Calculations were done with the help of the code CARI-6M. Such parameters as flight route, solar activity, duration and altitudes of flight were taken into account. Doses received during different flights and in different aircrafts were assessed. The results of measurements and calculations were compared and differences discussed. The results were also compared with the data obtained in other similar studies. **Results.** It was found that the highest doses are received in flights to Paris, London, Amsterdam, and Frankfurt by aircraft B737. A number of flights causing annual doses higher than 1 mSv was estimated. **Conclusions.** Despite the fact that only European flights are operated by Lithuanian Airlines the dose of 1 mSv may be exceeded under some circumstances. If it happens some radiation protection measures shall be taken. These measures are also discussed.

Key words:
Ionizing radiation, Radiation protection, Aircrews

INTRODUCTION

Humans are affected by various sources of ionizing radiation. Doses induced by these sources, variations of these doses, their relationship with different parameters, and possibilities to decrease the doses are different. The doses and related parameters are under close surveillance [1]. The aim of the surveillance is to determine magnitudes and pathways of exposures to optimize radiation protection, i.e., to achieve the doses and the number of people being exposed as low as reasonably achievable, taking account of social and economic factors.

Aircrews flying on commercial altitudes are exposed to cosmic radiation of the intensity higher than that at the sea level. For this reason members of frequently flying aircrews can receive doses which are significant from the point of view of radiation protection. According to the European Council Directive (96/29/Euratom) on basic radiation protection standards, these doses are to be estimated

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and if necessary the appropriate radiation protection measures have to be taken [2].

The composition of the radiation field in the atmosphere is defined by the galactic cosmic radiation with exception of very rare solar flares [3]. The galactic cosmic radiation comes from sources outside the solar system. It consists of protons, ions and electrons. The earth atmosphere is a good shield, which protects life on the surface of the earth against radiation. Only a small part of this radiation, after numerous losses of energy and changes in its type due to interactions in atmosphere, reaches the surface of the earth. According to our estimations, the annual effective dose due to cosmic radiation of the Lithuanian population on the surface of the earth is 0.38 mSv. This dose though rather significant in comparison with doses from other sources cannot be decreased and thereby is excluded from a regular control.

It was found long ago that the dose rate increases with increasing altitude. This increase is particularly observable at altitudes higher than 8000 m. The reason for this is the decrease in the thickness of the layer of the atmosphere that effectively protects against cosmic radiation [4]. Due to this fact the dose rates at altitudes of commercial flights exceed those at the sea levels by a factor of ten and more. Radiation at high altitudes differs from the one at the sea level also by its composition; neutrons are as important as other components, such as protons, electrons, photons and electrons [5]. For this reason, it is important to assess doses caused by neutrons at altitudes of commercial flights as the dose caused by neutrons at the sea level is relatively well known [1].

The so called stochastic effects, cancer and genetic changes, may occur as a result of these exposures, which are too low to cause deterministic effects, radiation sickness, cataract or skin burns. Probability of stochastic effects depends on the magnitude of effective dose. The amount of ionizing radiation absorbed by human body, the relative efficiency of impact of ionizing radiation and radiosensitivity of different organs and tissues are taken into account when determining the effective dose. Due to limited space and scope of this paper, the detailed explanation of the concept of effective dose is not given. It is enough to say that probability of death due to the impact of ionizing radiation is equal to 5% per 1 Sv of effective dose.

Determination of doses in a flying aircraft may be done by both calculations and direct measurements which employ different techniques and equipment [6–9]. The techniques of measurements vary from rather sophisticated, which take into account differences between energetic properties of cosmic radiation to those used in routine monitoring of exposure at the sea level. Calculations and measurements rather compliment than exclude each other. The use of alternative techniques helps to receive more accurate results.

The aim of this study was to determine effective doses, which can be received by members of aircrews of Lithuanian Airlines in different flights and to identify radiation protection measures, which are to be taken to protect these persons.

MATERIALS AND METHODS

In this study, the ionizing radiation doses received by members of aircrews of Lithuanian Airlines were both calculated and recorded. Calculations were performed with the help of the computational code CARI-6M released by the Civil Aeromedical Institute of the Federal Aviation Authority of the USA. This code is freely available and can be downloaded from the Internet. The following parameters are to be entered for calculations: origin and destination of the flight, flight profile, duration of flight at different altitudes, month and year of flight.

The code calculates effective doses in defined flights.

Direct measurements of doses were performed by several different techniques.

Doses due to direct ionizing particles were recorded by both thermoluminescent dosimeters (TLDs) and Geiger Muller (GM) counters.

The use of TLDs for dose measurements is based on ability of some materials (e.g., lithium fluoride, LiF) to retain for a rather long time the information “recorded” by ionizing radiation. When such a material is heated it radiates a visible light whose intensity is proportional to radiation absorbed. TLDs from the RADOS Co. routinely used in personal dosimetry, were flown for 20–30 times along the same route. After read-out, the average doses in each route were estimated.

TLDs are calibrated in terms of personal dose equivalent $H_p(10)$ with Cs-137 source. LiF was used for measurements. Since the fading of this type of dosimeters does not exceed 3% per month its effect has not been taken into account.

More detailed measurements were performed by GM counters. Operation of GM counters is based on ability of ionizing radiation to ionize gas. The amount of ionization reflects the absorbed dose and thereby is recorded. Gamma Expert by Genitron Instruments GmbH was used for these measurements. The device records the dose rate within the determined periods of time and stores the information in its memory. Later on this information is read-out by computer. This technique is particularly helpful when variations of the dose rate are to be recorded.

The factory calibration of GM counters in terms of ambient dose equivalent (with the help of Cs-137 source) was used.

As mentioned above, the neutron radiation is also important at high altitudes. For this reason the neutron dose meter (rem counter) from the Eberline manufacturing company was used. The principle of the meter operation is based on the interaction of neutrons with boron. Neutrons are slowed down by polyethylene sphere, surrounding the boron layer. Due to interactions of neutrons with this layer alpha particles are generated. They are recorded by a proportional counter (the principle of this counter operation is similar to that of GM counter).

The standard neutron rem counter calibrated with plutonium beryllium (PuBe) source was used. Maximum dose rates and total doses were recorded.

Any attempt has been made to make the measurements as automated as possible. However, in all dose measurements the flight date and time were recorded by members of aircrews. In neutron dose measurements, the readings of a neutron dosimeter were also recorded by instructed members of aircrews. Short descriptions of procedures have been prepared to facilitate the task.

RESULTS

Measurements were performed in the regular and chartered flights of Lithuanian Airlines in 2000–2001.

Although the optimized approach to this kind of study suggests the determination of typical doses in different flights, it cannot be easily followed since there are some parameters, which influence the magnitude of exposure.

One of such parameters is geographical latitude. The dose rate and doses increase with latitude if it is lower than 50°. Figure 1 illustrates this fact, where the dose rate due to directly ionizing particles is given for the flight Las Palmas – Vilnius.

Another important parameter, which has an impact on the dose rate is, as mentioned above, the altitude of flight. It is evident in Figure 2, which depicts variations of the dose rate when the aircraft was flying at different altitudes.

The dose rate in an aircraft also depends on solar activity – the higher the solar activity the lower the dose rate. The only exception are solar flares when the dose rate increases with increasing solar activity. However, these

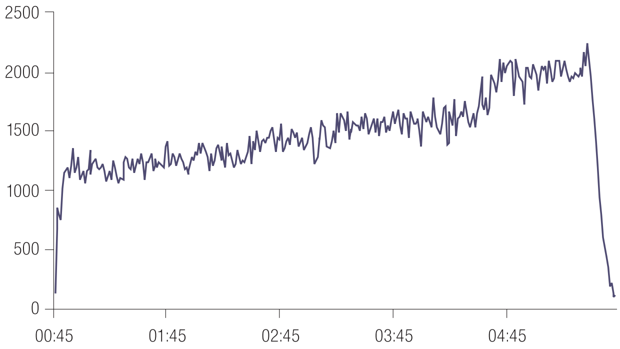

Fig. 1. Variations of dose rate (nSv/h) due to directly ionizing particles in the Las Palmas – Vilnius flight. Aircraft – Boeing 737. Time is given at the horizontal axis. Results obtained with Gamma Expert.

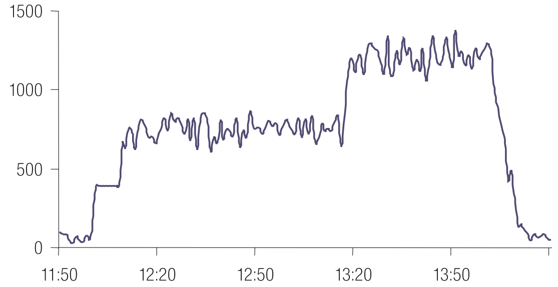

Fig. 2. Variations of dose rate (nSv/h) due to directly ionizing particles in the Paris – Vilnius flight. Aircraft – Jak 42. Time is given at the horizontal axis. Results obtained with Gamma Expert.

flares are very rare events of short duration and their influence on annual doses is not so important, therefore they were not analyzed in this study. But periodic variations of solar activity are of much greater importance to doses received by members of aircrews. This can be seen in Figure 3, where variations of the calculated dose are given. The dose was calculated for the Vilnius – London flight, the altitude of FL350 (Flight Level of 35 000 feet), for each month in 1991–2002. The highest solar activity within the period under consideration was in 1992, and the lowest in 1996–1998.

As seen the current measurements of doses were performed when solar activity and doses were in the middle of the range of their possible values. It means that in some years these doses can be higher by approximately 25%. Similarly, in periods of higher solar activity these doses can be lower by the same factor.

Different flight conditions during different flights complicate the task of determining doses typical of different flights. For example, the measurements of doses due to directly ionizing particles in 12 one-way flights, between Vilnius and London at altitudes of FL310 to FL350, during the period from September 23 to October 10, 2000, gave an average dose equal to 3.8 ± 0.58 μSv. The uncertainty is given for 95% of confidence and is equal to approximately 15% of the average. It indicates that even within a short period of time the doses received on the same route might differ rather significantly. This fact was the reason for using few means of determination of typical doses in different flights.

Dose averages were assessed using the results produced by different means: calculations and measurements by TLDs, GM counters and neutron dose rate meter. Table 1 summarizes the results of measurements and calculations.

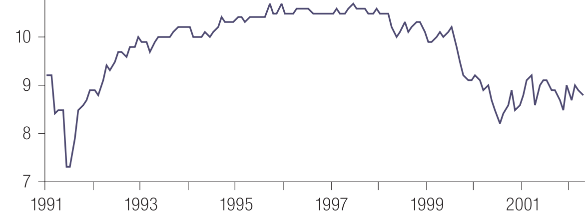

Fig. 3. Variations of dose (μSv) in the Vilnius – London flight due to changes in solar activity. Calculated with CARI-6M.

Table 1. Measurements and calculations of doses in different round trip flights

Flight	Aircraft	Effective dose (μSv)	
		Measured	Calculated
London	B 737	7.3	7.8
Las Palmas via Barcelona	B 737	11.8	14.8
Frankfurt	B 737	5.4	6.2
Copenhagen	B 737	4.2	2.8
Amsterdam	B 737	6.5	5.6
Antalia	B 737	11.2	7.0
Helsinki	SAAB 2000	3.1	2.1
Frankfurt	SAAB 2000	4.7	4.8
Berlin	SAAB 2000	5.5	2.8
Tallinn	SAAB 2000	2.6	1.4
Kiev	SAAB 2000	2.8	1.5
Stockholm	SAAB 2000	7.2	2.4
Copenhagen	SAAB 2000	5.1	2.6
Moscow	Jak 42	2.4	2.5
Vladikaukaz	Jak 42	4.5	6.4
Tallinn	SAAB 340	1.9	0.6
Warsaw	SAAB 340	3.5	0.4

As seen in Table 1, in some cases the differences between calculated and measured doses are rather large. Most frequently, the measured doses were higher than the calculated ones. Besides, larger differences are most common in shorter flights.

In many cases, doses recorded by a neutron rem counter contribute mostly to the total doses. This might be explained by larger errors made during recording of lower doses, although rem counters show a tendency to underdetermine neutron doses at flying altitudes.

As concerns the measured doses due to directly ionising particles, background radiation at lower doses has also an essential impact on the results. It is illustrated by the fact that the differences between doses recorded by TLDs and GM counters in the same flight are larger for short flights (the ratio of doses recorded by these tools is up to 2.2), whereas in longer flights, e.g., to/from London or Frankfurt, these differences are smaller (the ratio is up to 1.05). Usually, TLDs gave higher doses than GM counters.

Differences between measured and calculated doses are also found in other studies. For example, Bagshaw [10] gives data on doses measured in Boeing 747–400, flying directly from London to Tokyo. The measured dose rates were around 6 μSv/h vs 3.7 μSv/h estimated by CARI 3Q. It is evident that different methods used jointly give a better assessment of the aircrews' exposure, particularly if doses received in short flights are to be assessed and common measurement tools are used.

Due to the differences discussed above, the values obtained by some means, which differed by more than 50% from the appropriate values obtained by other means, were not taken into account when calculating the averages.

The results for different aircrafts are given in Tables 2–5. It is evident that the doses depend on flight and type of an aircraft. Since shielding properties of different types of aircrafts are similar, taking into account rather high penetration capability of radiation at altitudes of commercial flights, the main reason for these differences might be different altitudes, geographical latitudes and duration of flights taken by different aircrafts.

For this reason the comparison of our results with those obtained in other studies in other airlines might be somewhat difficult, although the general situation is the same from flight to flight of different airlines.

It might be indicative to compare the dose rates received at flying altitudes. The results for Lithuanian Airline*s* are given in Table 6.

According to Waters et al. [11], the dose rate ranges from 0.91 to 6 μSv/h. The range of 3–4 μSv/h is given by Spurny et al. [9]. This indicates that the results obtained in the present study are consistent with other data.

The main indicator used when deciding what radiation protection measures should be taken are the annual doses received by individuals. Numbers of flights, which may cause doses higher than 1 mSv were calculated. The results of these calculations are given in Table 7.

Although Lithuanian Airlines operate relatively short flights, in some cases annual doses to individuals, members of aircrews, can approach or even exceed 1 mSv. The largest doses are received in regular flights like Vilnius

Table 2. Average effective doses in different round trip flights by aircraft B 737

Flight	Effective dose (μSv)
London	7.6
Las Palmas via Barcelona	13.4
Frankfurt	5.5
Copenhagen	3.5
Amsterdam	6.1
Antalia	9.1

Table 3. Average effective doses in different round trip flights by aircraft SAAB 2000

Flight	Effective dose (μSv)
Helsinki	2.6
Frankfurt	4.7
Berlin	3.0
Tallinn	2.0
Kiev	2.1
Stockholm	2.7
Copenhagen	2.7

Table 4. Average effective doses in different round trip flights by aircraft Jak 42

Flight	Effective dose (μSv)
Moscow	2.4
Vladikaukaz	5.4
Paris	6.5

Table 5. Average effective doses in different round trip flights by aircraft SAAB 340

Flight	Effective dose (μSv)
Tallinn	0.7
Berlin	1.2
Warsaw	0.5

Table 6. Dose rates at flying altitudes in different aircrafts

Aircraft	Range of dose rates (μSv/h)
B 737	2.5–5.4
SAAB 2000	2.6–4.8
Jak 42	2.1–2.6
SAAB 340	0.6–0.8

Table 7. Numbers of round trip flights which result in 1 mSv of effective dose

Flight	Aircraft	Number of flights
London	B 737	130
Las Palmas via Barcelona	B 737	80
Frankfurt	B 737	180
Copenhagen	B 737	290
Amsterdam	B 737	160
Antalia	B 737	110
Helsinki	SAAB 2000	390
Frankfurt	SAAB 2000	210
Berlin	SAAB 2000	330
Tallinn	SAAB 2000	500
Kiev	SAAB 2000	480
Stockholm	SAAB 2000	370
Copenhagen	SAAB 2000	370
Moscow	Jak 42	420
Vladikaukaz	Jak 42	190
Paris	Jak 42	150
Tallinn	SAAB 340	1430
Berlin	SAAB 340	830
Warsaw	SAAB 340	2000

– London, Vilnius – Amsterdam, Vilnius – Frankfurt and Vilnius – Paris. A probability that 1 mSv will be exceeded by aircrews flying aircraft SAAB 340 is close to 0.

DISCUSSION

The calculations and measurements show that the annual effective doses received by at least some members of the Lithuanian Airlines aircrews fall within the limit of 1 mSv.

Different studies often report similar data. Wilson et al. [12] report that annual doses to crews of subsonic long haul flight by Air France are 2–3 mSv. Doses received by crew members of the Australian commercial domestic flight are in the range of 1–1.8 mSv per year [13].

Potential doses might be assessed more precisely taking into account an actual number of flights performed annually by members of aircrews. However, the results given in this paper can help to determine possible doses very easily because the basis for this determination, doses in different flights, is already provided.

When assessing possible annual doses, the fact that measurements and calculations were performed in the period of modest solar activity should be taken into account. In periods of the lowest solar activity, typical flight doses will be higher by approximately 25%, and thus a lower number of flights will be needed to receive 1 mSv.

If the effective dose exceeds 5 mSv in a consecutive 5-year period (1 mSv per year on average), the special radiation measures should be taken, e.g., members of aircrews should be informed about possible risk associated with exposure, and which must be taken into account when setting flight schedules.

Special attention should be given to the protection of female aircrews. Women at the child-bearing age should be encouraged to inform the employer when they become pregnant. In such a case the work of pregnant woman should be organized in a manner that assures the lowest possible dose to the fetus, unlikely to exceed 1 mSv, during the remainder of pregnancy.

It is improbable that the annual effective doses received by members of aircrews could exceed 6 mSv. It might be possible only if Lithuanian Airlines would have started operating long haul flights, e.g., across the Atlantic.

It might be expedient to repeat in future a similar exposure assessment survey using other techniques and measurement tools. For example, Curisio et al. [14] have drawn the conclusion that the repeated measurements on the same route are highly consistent.

A growing attention is given to the protection of humans against different hazardous effects. Ionizing radiation is not an exemption. A new approach to the protection of aircrews against cosmic radiation is one of such examples. Traditional radiation protection measures, which are used in medicine, industry or nuclear energy production, are not applicable to aircraft operations. Members of aircrews cannot wear personal dosimeters and no additional shielding can be employed to protect them. Therefore, the measures discussed above may prove to be effective.

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