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REVIEW ARTICLE

IONIZING RADIATION AS A RISK FACTOR FOR CATARACT DEVELOPMENT IN THE OCCUPATIONAL SETTING OF A PROFESSIONAL PILOT

Aleksandra OSTROWSKA-SPALENIAK[1], Katarzyna KRZEMIŃSKA[2], Grzegorz KADE[1], Sebastian SPALENIAK[3]

[1] Military Institute of Aviation Medicine, Warsaw, Poland

[2] Military Medical Institute – National Research Institute, Warsaw, Poland

[3] Department of Internal Diseases and Nephrodiabetology, Medical University of Lodz, Poland

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Author's address: S. Spaleniak, Department of Internal Diseases and Nephrodiabetology, Medical University of Łódź, ul. Żeromskiego 113, 90-549 Łódź, e-mail: sebastian19860@op.pl

Abstract: Pilots and aircraft crew members are occupationally exposed to higher doses of ionizing radiation than the general population. This paper presents national regulations concerning employee protection, specifies measurement methods that may be used to determine the absorbed dose. It analyzes the impact of ionizing radiation on the organ of vision, in terms of the potential development of cataracts. It details the conditions for qualifying a candidate for employment as a pilot in the Armed Forces of the Republic of Poland, with regard to ocular diseases.

Keywords: ionizing radiation, aviation, cataract, dosimetric methods

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INTRODUCTION

Ionizing radiation is defined as radiation which, when penetrating a medium—in the case of humans, tissues and water—causes the formation of electric charges, i.e., ionization. Ionizing radiation can be divided into alpha, beta, and gamma radiation. They are distinguished from each other by their ability to penetrate matter.

Ionizing radiation is widespread and present around us as cosmic radiation; we also encounter it in baggage screening devices at airports, in X-ray machines, and in computed tomography. Apart from its use in medicine, it also has teratogenic effects. Depending on the level of radiation exposure, one may expect symptoms of acute radiation sickness (as in the Chernobyl explosion), whereas lower doses may increase the risk of developing cataracts or other ocular diseases.

The aim of this study was to determine the exposure to ionizing radiation in the work of a pilot, in terms of the potential risk of developing cataracts.

Exposure to Ionizing Radiation in the Work of a Pilot

The level of ionizing radiation during an airplane flight depends, among other factors, on geomagnetic latitude, solar radiation, and altitude above sea level at which the aircraft is operating. For example, military pilots flying turbojet aircraft are more exposed to ionizing radiation than pilots of charter flights, with a particularly noticeable increase occurring between 10 and 16 kilometers above sea level.

Studies conducted by Polish Airlines concerning cosmic radiation have shown that the maximum doses for a single flight were slightly below 70 µSv, while typical values for long-haul flights ranged between 35–40 µSv.

In Poland, it is considered that the average radiation dose from natural sources is approximately 2.5 mSv (millisievert—a unit and physical quantity referring to the effect of ionizing radiation on living organisms). This means that personnel who spend several hundred hours per year in the air—such as aircraft pilots and flight attendants—receive a dose approximately twice as high, falling within the range of about 2–6 mSv [4].

Aircraft personnel are therefore more exposed to radiation than medical personnel, who, in principle, can use personal protective equipment.

Ionizing Radiation Absorbed by Residents of High-Altitude Locations

Given that the dose of cosmic radiation depends on elevation above the Earth's surface, different absorbed dose values are observed depending on altitude above sea level. For instance, a resident of Szczecin (elevation 0 m a.s.l.) receives an annual dose of 0.33 mSv, whereas a resident of Bukowina Tatrzańska (1000 m a.s.l.) receives an annual dose of 0.51 mSv. Even more interesting is the situation in the capital of Bolivia—La Paz is the highest capital city on Earth (3630 m a.s.l.), where the annual dose absorbed by a resident amounts to approximately 1.5 mSv, which is comparable to the dose received by an aircraft crew member [3]. This raises the question of whether the absorbed doses of radiation related to occupational exposure may contribute to increased morbidity among pilots and other members of aircraft crews.

Impact of Ionizing Radiation on the Organ of Vision

The body's response to ionizing radiation depends, among other factors, on its penetration capability, the dose and its intensity, the type of exposure (single or prolonged over time), age, individual sensitivity, and relative biological effectiveness. The sensitivity of cells to radiation increases with higher proliferative activity and lower tissue differentiation.

Radiation-induced complications affecting the organ of vision may involve various parts of the eye: the cornea, the lens, the retina, the optic nerves, and the lacrimal glands. These are considered critical organs—for each, maximum permissible radiation doses have been defined: for the lens, 10 Gy (gray, the SI unit of absorbed dose); for the retina, 45 Gy; for the optic nerves, 54 Gy; and for the lacrimal gland, 30–40 Gy. Doses in the range of approximately 5–8 Gy cause conjunctival hyperemia, ulceration, and radiation-induced corneal damage. This begins with punctate epithelial defects, followed by stromal edema and aseptic radiation necrosis. Damage to the lacrimal gland contributes to the development of dry eye syndrome due to impaired tear production, which in turn leads to further damage to the eyelid and corneal epithelium, making them more susceptible to injury and infection. Radiation-induced damage to these structures may result in numerous disorders, often including vision loss. In addition, less frequently observed complications include uveitis, retinal hemorrhages, optic disc edema, and central retinal vein thrombosis. This constellation of symptoms is referred to as radiation retinopathy [11,18].

The lens of the eye is one of the most radiosensitive structures in the human body. Excessive exposure of this part of the visual system to ionizing radiation may induce a radiation-induced cataract. However, in some cases, many years may pass after exposure before the cataract becomes clinically apparent. This latency period depends, among other factors, on the radiation dose and the age of the individual; younger individuals are more sensitive because their lens cells exhibit more active growth. Ionizing radiation in the form of X-rays or gamma rays may cause cataract formation in some individuals even after a single exposure to a dose ranging from 2 to 10 Gy (a routine chest X-ray involves an exposure of approximately 0.1–2.5 mGy), without any other ocular symptoms. A similar effect can be induced by neutron radiation at doses more than 50% lower [14].

Cataract is a typical tissue reaction (deterministic effect) resulting from exposure to ionizing radiation, for which preventive dose limits have been recommended in the radiological protection system. According to the 2012 recommendation of the International Commission on Radiological Protection (ICRP) regarding the significant reduction in the annual equivalent dose limit for the lenses of the eyes of individuals occupationally exposed to ionizing radiation, the recommended dose limit, expressed as effective dose, is 20 mSv per calendar year; for the general population, the limit is 15 mSv [12].

Symptoms of radiation-induced cataract may vary between individuals, and potential individual predispositions remain uncharacterized. The first clinical signs of radiation-induced cataract—resulting from damage to the lens capsule epithelium—often include punctate opacities in the area of the posterior lens capsule and feathery anterior subcapsular opacities that spread in a cup-like pattern toward the lens equator. The zone of radiation-sensitive cells consists of mitotically active cells located at the lens periphery, approximately 1 mm anterior to the equator and 3–4 mm from the center of the lens [6]. The opacification process may progress to complete lens opacity. Ionizing radiation was initially associated primarily with posterior subcapsular cataract. However, it has been proven that it can also induce cortical cataracts and may accelerate the initiation or progression of nuclear cataracts [18]. The latency period varies and may range from 3–6 months to several years.

Ionizing radiation is constantly present in the human environment, primarily due to the omnipresence of radioisotopes of various elements in nature and cosmic radiation. Its potential impact on the visual system becomes increasingly significant under specific occupational conditions, including those encountered by military pilots. Despite the fact that modern aviation is becoming less dependent on human factors, the pilot remains a critical component of the aviation system, and the proper function of the visual system is of key importance to flight safety.

Most epidemiological studies on cataract occurrence focus on older age groups, while significantly fewer data exist regarding early cataract development among individuals of working age—among whom flight crew members constitute a substantial portion. Mild and early lens opacities may cause significant glare and haziness, as well as changes in color perception, which can impair pilot performance even in the absence of reduced visual acuity.

The appearance of cataracts as a consequence of occupational exposure in flight crew members has been a major topic of interest in aviation medicine in recent years, due to numerous reports of flight-associated diseases. Due to multiple confounding variables, it has been difficult to determine whether an increased risk of cataracts can be directly attributed to the aviation environment, particularly to additional radiation exposure during flight.

Studies conducted among military aviators from the United States Air Force (USAF) and United States Navy (USN), as well as American astronauts at the NASA Space Center, indicated that military aviators with cataracts tend to be younger on average at the time of diagnosis compared to astronauts with cataracts. However, the incidence of cataracts was found to be higher in astronauts than in military aviators. Cataracts in USAF and USN aviators were most commonly located in the posterior subcapsular region of the lens, while cataracts in astronauts most likely originated in the cortical zone [9]. Another study involving pilots also demonstrated associations between cataracts in other locations (including nuclear cataracts) and exposure to ionizing radiation, with cosmic radiation exposure tripling the risk of nuclear cataract formation [1].

In Poland, within the framework of military medical assessment, regulations established by the Ordinance of the Minister of National Defense of March 25, 2024, concerning the assessment of fitness for military service and the procedures of military medical boards in such matters, impose strict evaluation criteria for military flight personnel, including for visual system disorders as outlined in Annex 2, Chapter IV of the aforementioned ordinance [16]. Health groups are divided into flight personnel – pilots (Group IA, IB, IC), cabin crew (Group II), and ground personnel supporting flight operations (Group III) (Fig. 1). Categories of fitness for service are defined as “Z” – fit, “N”

Paragraph	Point	Disease and disability	Health groups				
			pilots			cabin crew	flight safety personnel
			IA	IB	IC	II	III
1	2	3	4	5	6	7	8

Fig. 1. Division of health groups in accordance with Annex 2 of the Ordinance of the Ministry of National Defense dated March 25, 2024 [16].

14	3	Lens opacity not impairing vision with preserved normal visual acuity	Z/N	Z/N	Z/N	Z	Z
	4	Progressive lens opacity with decreasing visual acuity	N	N	N	Z/N	Z/N
	5	History of cataract surgery with implantation of an intraocular artificial lens	N	Z/N	Z/N	Z	Z

Fig. 2. List of diseases and defects with corresponding service fitness categories based on the group assessed, as per Annex 2 of the Ordinance of the Ministry of National Defense dated March 25, 2024 [16].

– unfit, and "Z/N" – the category is determined depending on specific conditions and detailed explanations of the regulation.

According to the regulation, flight personnel (pilots) diagnosed with the condition described in §14.3: "Lens opacities not impairing vision, with preserved normal visual acuity," are classified as Z/N in Groups I, II, and III; in the case of cabin and ground personnel (Groups II and III), the classification is Z. If §14.4 applies – "Lens opacities with progressive tendencies and decreased visual acuity," the classification is N in Groups I, II, and III, and Z/N in Groups II and III. A history of cataract surgery with implantation of an artificial intraocular lens (§14.5) eliminates eligibility for service in Group I, and conditionally permits service in Groups II and III, with classification as Z/N (Fig. 2).

In addition to obvious physical factors (e.g., dose, dose rate, radiation quality, irradiation volume), potential modifiers of the individual response to radiation-induced cataract include sex, age, and genetic predispositions. Comorbidities and combined exposures also play an important role.

In the context of occupational environments, further consideration is needed as to the extent to which work involving exposure to ionizing radiation affects the functionality of sensory organs, which are critically important for the proper performance of duties—especially in the case of flight personnel. This important aspect is of particular professional significance for active, young pilots, as it may determine their ability to carry out tasks in the flight environment. Further research and consensus are necessary to gain deeper insight into the factors determining individual responses to radiation-induced cataracts and their implications for the protection of, among others, flight crews from the biological effects of radiation in the future [2].

Radiological Protection of Workers

Aircraft crews represent the occupational group most exposed to ionizing radiation, which is why national Atomic Law regulations have placed this group under dosimetric monitoring. One of the fundamental principles stemming from Atomic Law and international organizations is the optimization of exposure, aimed at minimizing both the number of exposed workers and ensuring that the doses of ionizing radiation received are as low as reasonably achievable.

This legislation stipulates that a worker may be permitted to work under conditions of exposure to ionizing radiation only after receiving a positive opinion in initial preventive medical examinations.

Each employee performing official duties under such exposure must be classified by the head of the organizational unit into the appropriate exposure category based on the annual absorbed dose. If the effective dose exceeds 6 mSv, or if the worker is exposed to an equivalent dose of 120 mSv to the lens of the eye, or 150 mSv to the skin or bones, then the worker is classified into Category A. All others not qualifying for Category A fall under Category B. This classification results in differing exposure assessment methods: individual dosimetric measurements for Category A workers, and environmental dosimetric measurements for Category B workers [12].

Medical supervision includes preventive health examinations—initial and periodic. According to the Regulation of the Minister of Health and Social Welfare, the frequency of periodic examinations is annual for Category A and every three years for Category B. As part of the mandatory preventive examinations, the occupational health physician conducts a general medical check-up and orders additional tests, including: complete blood count with differential, reticulocyte count, and ophthalmologic consultation with an eye examination focused on evaluating lens transparency [15].

The duties of an aircraft operator in the scope of radiological protection, in cases where crew members are exposed to an effective ionizing radiation dose exceeding 1 mSv annually, include assessing the potential doses that may be received during flights. Moreover, within the flight scheduling process, the expected radiation dose must be estimated and considered in crew assignment to ensure that no crew members who might exceed dose limits are assigned to such flights. An essential responsibility of the aircraft pilot is to educate the crew about the potential health risks associated with radiation exposure, with special emphasis on female crew members of childbearing age, encouraging them to report any potential pregnancy. Work duties must then be adapted accordingly. For the unborn child, the equivalent dose should be kept to a minimum and must not exceed 1 mSv for the entire pregnancy [12].

Dosimetric Methods

In dosimetric instruments, the measurement of radiation is performed by various types of detectors. Passive detection methods are based on measuring the absorbed dose over a unit of time. It is not possible to read the result immediately—analysis is carried out in a laboratory after the dosimeter has been exposed to a radiation environment and absorbed a dose. The advantages of such measurement devices include their low cost, no need for a power supply during measurement, and small size, which makes them suitable for use as personal dosimeters [10]. Examples of such dosimeters include photometric dosimeters and thermoluminescent dosimeters. The latter type is used to determine the dose of radiation absorbed by the lens of the eye (eye dosimeter) or the skin (wrist or ring dosimeter) [5].

Active detection methods are based on real-time measurements, allowing the data to be read at the moment the radiation is detected. Additionally, some dosimetric instruments have the capability of data logging via internal memory systems, making it possible to read cumulative dose values. This category of devices includes, for example, gas detectors such as the Geiger-Müller counter, or semiconductor detectors [10].

Both types of detection are effective for measuring absorbed radiation dose, but they do not reflect the biological effect that ionizing radiation may cause. For that purpose, biological dosimeters are used.

Ionizing radiation, when interacting with living organisms, can cause molecular and cellular damage. Living organisms are equipped with repair mechanisms that serve to counteract the damage incurred. However, these mechanisms are not always effective, and the damage caused by ionizing radiation can lead to structural changes in chromosomes, resulting in chromosomal aberrations. Chromosomal aberrations can be divided into stable and unstable types. Unstable aberrations tend to diminish over time due to the absence of further exposure to the inducing factor, whereas stable aberrations are passed on to daughter cells during mitosis and become fixed in the case of repeated exposure to the causative agent. Chromosomal aberrations in healthcare workers exposed to ionizing radiation in the course of their duties can be visualized by examining lymphocytes [13].

Another biomarker considered the gold standard in biodosimetry, and widely used among aircraft crew members, is the presence of dicentric chromosomes. These chromosomes form as a result of exposure to ionizing radiation and, notably, do not arise from exposure to electromagnetic fields [8], making them a reliable indicator in occupational groups exposed to both phenomena. The dicentric chromosome phenomenon is also observed naturally in part of the population; however, an increase in their frequency has been demonstrated after exposure to radiation during computed tomography (CT) scans [7,17].

In a study conducted by the Department of Radiological Protection of the Nofer Institute of Occupational Medicine in Łódź, measurements of absorbed radiation doses were performed using film dosimeters and thermoluminescent dosimeters. The study group included healthcare system workers, employees of regional sanitary-epidemiological stations, research institutions, and medical technology facilities. The results showed that in none of the studied groups were the annual average maximum doses exceeded. This outcome was also observed in the analysis of measurements from previous years. This indicates a high level of protection for healthcare workers [5].

CONCLUSIONS

The cited studies have shown that aircraft crew pilots are exposed to greater levels of natural ionizing radiation related to their profession than the general population. The absorbed doses range from 2 to 6 mSv per year. Among residents of areas located significantly above sea level, similar annual levels of absorbed radiation can be observed as those recorded in pilots' occupational exposure. This raises the question of whether these doses are significant in terms of health risk to the visual organ.

Ionizing radiation can affect any structure of the visual organ, but the lens is one of the most sensitive structures of the human body to such exposure. This exposure may contribute to the development of a radiation-induced effect known as radiation cataract. Cataract development is a long-term process, and the disease is typically associated with elderly patients, classified as senile cataract, although the condition can also affect younger individuals, including active pilots. Their lenses are more sensitive to radiation, as they are characterized by increased growth. Progressive clouding of the lens may lead to blurred vision, color perception disturbances, or visual acuity disorders—which may affect the quality of a pilot's performance and even flight safety. The cited studies confirmed an increased risk of developing cataracts resulting from ionizing radiation exposure. Therefore, Polish and European regulations have established effective dose limits for the eye lens, set at 20 mSv per year. Radiological protection of workers requires organizational unit managers to estimate the doses that aircrew members may receive during flights and to plan work schedules in a way that prevents exceeding established limits. Preventive medical examinations conducted under civilian and military aviation regulations define the conditions for approving a pilot for duty and the frequency of periodic examinations, which are intended both to assist occupational medicine physicians in assessing ongoing fitness for work, and to detect early changes that may arise due to occupational exposure. Dosimetric methods used to measure absorbed doses should be selected to optimally monitor individual exposure, and—due to the varying radiosensitivity of specific body structures—measurement methods should be developed for each specific organ. In the cited studies on radiation measurement methods among healthcare workers, a custom eye lens detector was developed.

The impact of radiation on the visual organ is undeniable. Due to the lack of personal protective equipment for workers, pilots and aircraft crews remain the most exposed occupational group to radiation. They are subject to radiological protection, yet further studies are needed to assess the biological effects on the human body and visual organ, to improve measurement methods, and to develop a protection system for aircrew against this radiation. Such steps will contribute to reducing the impact of radiation on pilots' health and, consequently, will also lower the risk of health complications associated with professional activity.

AUTHORS' DECLARATION

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REFERENCES

1. Ainsbury EA, Barnard S, Bright S, Dalke C, Jarrin M, Kunze S, Tanner R, Dynlacht JR, Quinlan RA, Graw J, Kadhim M, Hamada N. Ionizing radiation induced cataracts: Recent biological and mechanistic developments and perspectives for future research. Mutat Res Rev Mutat Res 2016; 770(Pt B): 238-261. doi: 10.1016/j.mrrev.2016.07.010.
2. Barnard SGR, Hamada N. Individual response of the ocular lens to ionizing radiation. Int J RadiatBiol 2023; 99(2): 138-154. doi: 10.1080/09553002.2022.2074166.
3. Bilski P. Latać czy nie latać. https://www.ifj.edu.pl/popularyzacja/do/2002/wyklady/bilski.pdf. (accessed: 10.12.2024).
4. Bilski P, Budzanowski M, Horwacik T, Marczewska B, Ochab E, Olko P. Raport Nr 1905/D Badania narażenia załóg lotniczych na promieniowanie kosmiczne – wyniki, wnioski i propozycje, Narodowy Instytut Fizyki Jądrowej im. Henryka Niewodniczańskiego. (accessed: 16.12.2024). www.ifj.edu.pl/badania/publikacje/raporty/2002/1905.pdf
5. Domienik-Andrzejewska J, Wiszniewska M. Dozymetria indywidualna jako element profilaktyki zdrowotnej pracowników narażonych na promieniowanie jonizujące. Med Pr Work Heath Saf 2023; 74(6): 527-39.

6. Filarska D, Czyżewska K. Uszkodzenie narządu wzroku po radioterapii – przegląd literatury Ocularcomplications of radiotherapy – the literatureoverview. Współczesna Onkologia 2000; 4(3): 109-110.

7. Golfier S, Jost G, Pietsch H, Lengsfeld P, Eckardt-Schupp F, Schmid E, Voth M. Dicentric chromosomes and gamma-H2AX foci formation in lymphocytes of human blood samples exposed to a CT scanner: a direct comparison of dose response relationships. RadiatProt Dosimetry 2009; 134(1): 55-61.

8. Herate C, Brochard P, De Vathaire F, Ricoul M, Martins B, Laurier L, Deverre JR, Thirion B, Hertz-Pannier L, Sabatier L. The effects of repeated brain MRI on chromosomal damage. EurRadiolExp 2022; 6(1): 12.

9. Jones JA, McCarten M, Manuel K, Djojonegoro B, Murray J, Feiversen A, Wear M. Cataract formation mechanisms and risk in aviation and space crews. Aviat Space Environ Med 2007; 78(4 Suppl): A56-66.

10. Kowalczuk K, Gazdzinski S, Leońska-Duniec A, Dziuda Ł, Maculewicz E. Which is the most reliable marker to assess the effects of cosmic radiation exposure in Polish military pilots: a mini review of literature. Pol J AviatMedBioeng Psychol 2023; 29: 10, doi: 10.13174/pjambp.18.12.2023.04.

11. Niżankowska MH. Okulistyka - podstawy kliniczne, Warsaw: PZWL, 2007.

12. Prawo atomowe (Journal of Laws 2024.1277).

13. Rana S, Kumar R, Sultana S, Sharma RK. Radiation-induced biomarkers for the detection and assessment of absorbed radiation doses. J Pharm BioalliedSci 2010;2(3):189-96.

14. Rękas M. Soczewka i zaćma. BCSC 11. Seria Basic and Clinical Science Course, Wrocław: Edra Urban &Partner; 2021.

15. Ordinance of the Minister of Health and Social Welfare of May 30, 1996 on conducting medical examinations of employees, the scope of preventive health care for employees, and medical certificates issued for purposes specified in the Labour Code.

16. Ordinance of the Ministry of National Defence of March 25, 2024 on determining fitness for military service and the procedure followed by military medical boards in such matters.

17. Stimpson KM, Matheny JE, Sullivan BA. Dicentric chromosomes: unique models to study centromere function and inactivation. Chromosome Res 2012; 20(5): 595-605.

18. Ziółkowska E, Zarzycka M, Meller A, Wiśniewski T. Powikłania oczne po radioterapii nowotworów regionu głowy i szyi – przegląd piśmiennictwa Ocular complications after external beam irradiation – a literaturę overview. Współczesna Onkologia 2009; 13(5): 251-254.