Aircrew Monitoring of Occupational Exposure to Ionising Radiation

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1. Legal situation in Europe

The Council Directive 96/29 EURATOM[1] laid down the protection from substantially increased exposure to natural radiation. In Article 42, this legal protection also includes aircrew personnel exposed to cosmic radiation. European Member States are required to transpose this requirement into adequate national regulations.

2. Aircrew monitoring

Operators of airlines are obliged to calculate the individual effective flight doses for every aircrew member who may exceed an occupational dose of one 1 mSv per year from cosmic radiation. In addition, airline operators have take measures to keep the dose of their personnel low by appropriate scheduling of missions and planning of flights. Furthermore, aircrew members are to be instructed about the nature of cosmic radiation exposure and its risk of adverse health effects, Through this legal requirement of dose monitoring and dose reduction, aircrew members receive now a legally based radiation protection that is equivalent to all other occupationally radiation exposed workers in terrestrial work-places.

In Germany for example, 45 airlines of various kind (scheduled or charter flights, air cargo, business jets, military etc.) calculate route doses of their personnel with computer programs and transmit the accumulated monthly doses though the Federal Office of Aviation to the Radiation Protection Register of the Federal Office for Radiation Protection.

3. Cosmic radiation

In order to understand reason and practice of aircrew monitoring it is useful to have a look at the nature of cosmic radiation.

The earth is permanently exposed to a steadily stream of high-energy atomic particles, that penetrate into the atmosphere. They have their origin from the depth of

[1] Council Directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the damages arising from ionising radiation

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the galaxy as well as from our sun. This stream of charged particles consists mainly of protons, helium nuclei and electrons. The impact of this cosmic radiation on the earth's atmosphere is not a constant one: shielded by the increasing density of the atmosphere, the ambient dose rate decreases with proximity to the earth's surface. The ambient dose rate also varies rhythmically within an eleven-years-cycle and changes geographically with the latitude. These two variations are caused by two protective mechanisms: the solar wind and the geomagnetic field that shields the earth against radiation from galactic particles.

The so-called ***"solar wind"*** is a continuous flux of charged particles, outgoing from the corona of our sun. A small part of the solar wind penetrates into the atmosphere. Primarily however, it diverts parts of the cosmic radiation off from our solar system. The intensity of the solar activity changes periodically in a cycle of some eleven years. During the maximum of the solar activity, a strong solar wind prevails and less galactic radiation can penetrate into the terrestrial atmosphere; at the solar minimum the solar activity is small and more galactic radiation can reach the earth's atmosphere. The last maximum of the solar activity was in the year 2000, the next solar minimum is expected around 2006/2007.

Already far outside of the terrestrial atmosphere, the ***geomagnetic field*** of our earth deflects parts of the electrically charged cosmic particles. This geomagnetic shielding works most effectively above the equator region: between the 30º latitude north and south of the equator, the magnetic field-lines are almost parallel to the earth's surface and deflect parts of the charged particles of cosmic radiation, so that only particles with very high-energy can penetrate into the atmosphere. At the geomagnetic poles however, which are about 1600 km remote from the geographical poles, the protective effect is weakest: between the 60º latitude and the geomagnetic poles, the charged cosmic particles intrude parallel to the geomagnetic field-lines into the atmosphere. As a result, the dose rate from cosmic radiation is higher in the northern and southern regions of the earth than around the equator.

Apart from the periodically changing solar wind occur ***solar particle events***, i.e. sudden solar eruptions that burst out instantly from the sun's corona by emitting intense radiation. They can produce abrupt increases of the solar x-ray or proton radiation or can cause intense geomagnetic storms, which may last for several hours or days. Occasionally, they are capable to disturb satellite-based telecommunication. In rare cases, primarily during the solar maximum, they can cause a substantial rise of the ambient dose rate in cruising altitudes of 10 – 15 km, particularly along the pole routes.

Those particles of cosmic radiation that penetrate into the upper atmosphere interact with atomic components of the air by creating high-energetic secondary radiation. The effective dose rate from cosmic and secondary radiation results in cruising altitudes up to some 40% from neutrons, 35% from protons and 25% from electrons, myons and photons. These percentage figures are only roughly approximated and vary particularly with altitude and latitude.

4. Radiation exposure and flying

The total effective dose on a flight depends primarily on

- cruising level,
- duration of the flight,
- flight route,
- solar activity and
- occurrence of solar flares.

At an altitude of 11 km and north of 60º latitude (Helsinki - Oslo - south point of Greenland) an effective dose rate from 6 to 7 µSv/h results from cosmic radiation. Above the equator region the dose rate reaches only one third of it because of the geomagnetic shielding. A flight from Frankfurt to New York (9 hours flight, with 8 hours at cruising level, in 2002) leads to an effective dose of approximately 50 µSv.

5. Dose calculation

Technically, it is possible to measure the dose rate during flight within the airplane. But as the physical conditions of cosmic radiation are well known, the doses can be sufficiently exact calculated by computer programs. These programs determine the entire effective dose en route, based on physical measurements and flight-determining data (e.g. flight date, departure and destination airport, flight profile and duration). In Germany, three programs are certified by the Federal Office for Aviation for the use of official dose calculation for aircrews (EPCARD, PCAIRE, FREE). Other Programs that are used in Europe are CARI and SIEVERT.

6. Exposure differences to other radiation workers

Aircrew members receive higher average doses than many other radiation exposed workforce in the classical occupational categories of medicine, nuclear fuel cycle, general industry or research and education. But they are not under the risk of exceeding dose limits l*et al*one receiving high single doses or even lethal overexposures, which may occur in radiation accidents. The maximum of the annual dose is hardly higher than 6 mSv and an exceed of 20 mSv/a can strictly be excluded.

Table 1. Aircrew monitoring and exposure in Europe[2].

Country	**Monitored Persons**	**Monitored Air lines**	**Collective dose (Pers.-Sv)**	**Mean annual dose (mSv)**	**Maximum annual dose (mSv)**
Czech Republic	1 480	5	3.3	2.2	3.5
Denmark	3 782	8	6.0	1.6	-
Germany	30 204	45	55.2	1.8	5.4
Finland	2 540	2	6.4	2.5	-
The Netherlands	12 140	2	16.0	1.3	< 6
United Kingdom	22 000	2	44.0	2.0	-

[2] Frasch G., Data from a survey among countries participation in the ESOREX project, 2005.

7. ALARA airborne - problems and limits

Exposure to cosmic radiation implies some peculiarities, which make it difficult to apply ALARA-principles in the same successful way as it is practiced in terrestrial workplaces. A jet-aircraft can hardly be shielded from cosmic radiation by technical means. Efficient technical radiation protection would require heavy shielding material, but aircraft construction is based on lightweight design. Protective clothing for aircrew member would be too heavy, uncomfortable to wear and unattractive in design; furthermore, its use would send adverse psychological signals of radiation risk to the passengers.

In terrestrial workplaces, practical protection measures against exposure from external radiation refer to distance, shielding and time. The attempt to transfer of these measures to the physical conditions that determine the dose during a flight would show the difficulties and limitations.

Table 2. Radiation protection principles on ground and airborne.

Protection principles in terrestrial workplaces	**Application airborne**	**Practical consequences**
Distance	cruising at lower altitudes	- increased fuel consumption, - increased costs, - increased air pollution
Shielding	flight routes along lower latitudes	- impractical - ineffective: longer routes cause more radiation exposure - (see above)
Time	less block hours	more trained part time staff economically not acceptable for people who make their living by full time employment

Being airborne, classical radiation protection measures are practically very limited. Article 42 of the Council Directive 96/29 EURATOM takes this into account by demanding appropriate measures with respect to working schedules and reduction of highly exposed aircrew. Thus, a transfer of ALARA-principles can only focus on

- mission planning for the crew members (e.g. appropriate mix of short-range and long-haul flights),
- en route optimisation (e.g. skipping of final clime-up).

However, putting this into practice lies primarily in the responsibility of airline management and pilots, as there are numerous other criteria of flight planning and safety to be considered.

8. Cosmic radiation and health risk

An epidemiological evaluation of possible health effects among aircrew members can be based on the European cohort studies on cancer mortality and incidence[3,4,5] and the recently published Iceland study on cataracta nuclearis.[6]

The studies show an increased mortality risk for the malignant melanoma among pilots and indicate this slightly for the cabin attendants. The risk for malignant melanoma is predominantly linked with exposure to ultra-violet solar radiation but not to ionising radiation, so that a life-style linked cause appears more probable than cosmic radiation.

Slightly enhanced mortality rates from breast cancer were observed among female flight attendants. A causal link to exposure to ionising radiation cannot be excluded principally. However, in the available studies, many of the known other risk factors for breast cancer have not been surveyed or sufficiently controlled, therefore, a final evaluation is presently not possible.

For leukaemia, as the best-proven radiation-related cancer risk, no significantly increased rates of incidence or mortality have been observed. The same accounts for other localization of cancer.

A possible detriment, which can be related to enhanced radiation exposure, is the cataract of the eye lens. A recently published study calculates an increased relative risk for elder pilots compared to non-pilots. In contrast to cancer illness the cataract of the eye lens has a different mechanism of causation and requires a threshold dose of more than 100 mSv.

In the cohort studies, the individual occupational lifetime dose of the examined aircrew ranged from an average of 15 mSv to a maximum of approximately 80 mSv. This is the order of magnitude, one would predict from the presently available dose monitoring data. If the radiation exposure of aircrew members remains within this order of magnitude, only a small statistical probability of radiation-induced illnesses would be expected. However, if the accumulated lifetime dose should rise in the future, the occupationally radiation induced health risks should be re-evaluated.

9. Risk communication

Exposure to cosmic radiation may develop to a sensitive topic to aircrew members as well as to frequent flyers and other members of public. The majority of flying personnel is female and many of them are of younger age. That implies that they may be exposed before or during the beginning of a pregnancy and that they can accumulate a comparatively high occupational lifetime dose. As dose monitoring of

[3] Blettner M., Zeeb H. et.al.: Mortality from cancer and other causes among male airline cockpit crew in Europe. Int J. Cancer. 2003 Oct 10;106(6):946-52.
[4] Zeeb H., Blettner M. et.al: Mortality from cancer and other causes among airline cabin attendants in Europe: a collaborative cohort study in eight countries. Am J Epidemiol. 2003 Jul 1;158(1):35-46.
[5] Rafnsson V., Sulem P., et al.: Breast cancer risk in airline cabin attendants: a nested case-control study in Iceland. Occupational and Environmental Medicine 2003;60:807-809
[6] Rafnsson V., Olafsdottir E. et.al.: Cosmic radiation increases the risk of nuclear cataract in airline pilots: a population-based case-control study. Arch Ophthalmol. 2005 Aug;123(8):1102-5

aircrew members is a new topic in radiation protection, radiation protectors are also at the threshold to a communication between the exposed persons, stakeholders (pilots, flight attendants and air lines) and last not least the public. Presently, it is unclear how the public discussion about exposure to cosmic radiation will develop. Therefore, it appears wise to remember the controversies and often sub-optimal discussions with stakeholders and the public in the nuclear power sector. Some lessons are meanwhile learned and can be applied to this new field:

- trustful co-operation between authorities, airlines and stakeholders,
- reliable dose calculation (quality standards for programs and guidelines for procedures),
- transparency instead of secrecy,
- avoid climate of distrust,
- early reimbursement instead of late compensation claims,
- comprehensible information,
- reasonable evaluation of exposure (comparison of doses from cosmic radiation with other natural and man-made sources).