Protection of air crew from cosmic radiation: Guidance material

(Version 3.1 - May 2003)

1. Introduction

1.1 The Council of the European Union adopted Directive 96/29 Euratom[1] (the Directive) on 13 May 1996. Article 42 of the Directive imposes requirements relating to the assessment and limitation of air crew members' exposure to cosmic radiation and the provision of information on the effect of cosmic radiation. Member States were required to implement the Directive by 13 May 2000.

1.2 The Air Navigation Order (ANO) has been amended to encompass the relevant articles of the Euratom Directive.

1.3 The obligations imposed by the Directive and mirrored in the ANO are expressed in general terms. The purpose of this guidance material is to assist operators by setting out in more detail some suggested means of compliance with those general obligations.

1.4 This guidance material draws upon the expertise of the National Radiological Protection Board, the Heath and Safety Executive (HSE), the Civil Aviation Authority (CAA), and several other sources. Further information is available from sources named in Section 11.

2. The Nature of Cosmic Radiation

2.1 Radiation is the transfer of energy from a source. It may be in the form of electromagnetic radiation such as x-rays and gamma rays. It may also be in the form of particles such as neutrons and protons. Cosmic radiation is the collective term for the radiation which comes from the Sun (the solar component) and from the galaxies of the Universe (the galactic component). Cosmic radiation is ionising, i.e. it can displace charged particles from atoms. This can lead to the disruption of molecules in living cells. Processes in the cell repair most of this damage. Cosmic radiation consists of a complex mixture of radiations and their interactions in the atmosphere are similarly complex. Nevertheless, the Earth's atmosphere substantially shields the Earth from cosmic radiation, and doses of cosmic radiation are greater with increasing altitude.

2.2 Cosmic radiation particles may be electrically charged and so may be deflected by the Earth's magnetic field, it is for this reason that doses of cosmic radiation are greater at higher latitudes towards the Earth's magnetic poles. The deflection of cosmic radiation particles is least for higher energy particles and for particles of all energies travelling parallel to the magnetic field lines. The deflection is greatest for lower energy particles such that apart from exceptional solar events, the solar component of cosmic radiation is of no direct concern. The output of radiation from the Sun varies in an approximate 11 year cycle. At times of maximum solar output, associated with increasing numbers of sunspots, the magnetic field embedded within the Sun's radiation serves to deflect more of the galactic cosmic radiation component away from Earth. For this reason doses are about 20% lower than the mean value during maximum solar activity and about 20 % higher during solar minimum. Mainly, but not exclusively, during solar maximum there is a small probability of a solar flare giving rise to exceptionally high numbers of energetic particles such that there are increased levels of cosmic radiation at aircraft altitudes.

3. Harmful Effects of Cosmic Radiation

3.1 All living things on Earth are exposed to a background level of radiation from naturally occurring substances both on Earth and in space (see paragraph 4.2). Additionally, there may be further exposure from man-made sources such as medical x-rays. There is direct evidence that high levels of radiation are harmful to humans. It is also believed that lower levels carry a risk which is in proportion to the dose. The risks from radiation exposure are detailed in the International Commission on Radiological Protection risk estimates[2] .

4. Doses from Cosmic Radiation

4.1 Ionising radiation is measured in terms of absorbed dose, the energy deposited per unit mass. Equal absorbed doses of different types of radiation cause biological effects of different magnitudes, and the sensitivity of different tissues of the body differ. To account for this, tissue absorbed doses are multiplied by radiation weighting factors to give equivalent doses, and by tissue weighting factors to give the effective dose in sieverts (Sv) to the whole body.

4.2 In the UK the average background radiation dose is 2.2 millisieverts (mSv) per annum. Such background radiation is not required to be taken into account when calculating occupational radiation exposure.

4.3 Cosmic radiation is made up of many different types of radiation of a wide range of energies and consequently is difficult to measure to a high degree of accuracy.

4.4 Cosmic radiation effective dose rates increase with altitude up to a maximum at about 20 km (66,000ft), and with increasing latitude reaching a constant level at about 50°. The effective dose rate at an altitude of 8 km (26,000ft) in temperate latitudes is typically up to about 3 microSv per hour (1000 microSv = 1 mSv) but near the equator only about 1 to 1.5 microSv per hour. At 12 km (39,000ft), the values are greater by about a factor of two.

5. Control of Occupational Exposure: General Considerations

5.1 Operators should make arrangements to give information and provide education regarding the risks of occupational exposure to radiation to their air crew, air crew being defined as flight crew, cabin crew and any person employed by the aircraft operator to perform a function on board the aircraft while it is in flight. Female air crew should be made aware of the need to control doses during pregnancy and to notify their employer if they become pregnant so that any necessary dose control measures can be introduced.

5.2 Air couriers and other exceptionally frequent flyers are not included in this Directive. Consideration of these categories of individuals may be undertaken at a European level in the future.

6. Control of Occupational Exposure in High Flying Aircraft

6.1 Aircraft capable of operating at altitudes greater than 15 km (49,000ft) should carry an active radiation monitor, which monitors current levels of radiation, to detect any significant short-term variation in radiation levels during flight. (This is to comply with other UK legislation and JAA requirements). Such variations may arise as a result of solar flares, or other solar events, which can cause a sharp increase in the solar component of cosmic radiation, especially at altitudes above 15km. Potential exposure resulting from such an event can be greatly reduced by a controlled descent if active monitoring is used. The galactic component of cosmic radiation, which is more important at lower altitudes, is not typically subject to large sudden changes.

6.2 Air crew operating such high flying aircraft should be subject to the same general monitoring regime as for those operating between 8 and 15 km but account should be taken of the greater potential variability of dose. Active monitoring may be used to assess the doses to which air crew are exposed (rather than using a computer program to predict dose) or simply to provide a warning of high dose rates.

6.3 In principle, the need to detect high dose rates could be achieved by some means other than an on-board monitor e.g. satellite or ground based solar monitoring systems. However, at present, such techniques provide no more than retrospective estimates of dose.

7. Control of Occupational Exposures of Pregnant Women

7.1 It should be noted that the provisions of Article 10 of the Directive apply to pregnant air crew and, once pregnancy is declared, the protection of the foetus should be comparable with that provided for members of the public. This means that, once the pregnancy is declared, the employer must plan future occupational exposures such that the equivalent dose to the foetus is unlikely to be greater than 1 mSv during the remainder of the pregnancy. The cosmic radiation exposure of the body is essentially uniform and the maternal abdomen provides no effective shielding to the foetus. As a result, the magnitude of equivalent dose to the foetus can be put equal to that of the effective dose received by the mother. Some operators have determined that pregnant aircraft crew should cease flying duties on declaration of pregnancy. This is with regard to the requirement of keeping doses low as reasonably achievable. It should also be noted that the practice of grounding crew from the moment they declare pregancy may be based on other aviation physiological risk factors to the mother and foetus, including circadian dysrhythmia, hypoxia, dehydration, noise, vibration and turbulence, mental fatigue and injury through manual handling and exertion. The HSE has produced a booklet INDG334 entitled "Working safely with ionising radiation: Guidelines for expectant or breastfeeding mothers". The document is on HSE's website at: www.hse.gov.uk/pubns/indg334.pdf. It is also available free from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA. Tel: 01787 881165, Fax: 01787 313995, website: www.hsebooks.co.uk.

8. Use of Computer Programs to Estimate Doses

8.1 Assessments of indivudals' exposures may be made using dose estimates for routes calculated using a computer program, combined with staff roster information. The data to be input are: the data of departure, the location of departure, the flight profile detailing the time in ascent, cruise and descent, and the arrival location.

8.2 There are several such programs, which are simple to use and have been validated. Once is produced by the Civil Aerospace Medical Institute in the United States (previously known as the Civil Aeromedical Institute), the latest version being CARI-6M. This is freely available from the US Federal Aviation Administration and is currently available as a download from the internet at http://www.faa.gov/education_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/download/index.cfm. A second was developed by GSF, National Research Centre for Environmental Health, Institute of Radiation Protection, Neuherberg, Germany on behalf of the European Commission. The program is known as EPCARD (European Package for the Calculation of Aviation Route Doses). The latest version is EPCARD 3.2 (February 2002) and is available on request (http://www.gsf.de/epcard/eng_start.php). A third, developed on the initiative of the French government agency, the Direction Generale de l'Aviation Civile, is known as SIEVERT (Systeme d'information a d'evaluation par vol de l'exposition au rayonnement cosmique dans les transport aeriens).All programs require regular updating, especially for the effect of solar modulation and for changes in geomagnetic field conditions.

8.3 Any program should be validated against experimental measurements. The use of computer programs is further detailed in guidance from the European Commission [3] .

8.4 Computer programs allow the calculation of dose estimates in advance and so predict where reduction of exposure needs to be planned (see paragraph 9.7). This preventive approach is recommended.

9. Acceptable Means of Compliance

9.1 Operators should ensure that studies are carried out so as to assess the likely magnitude of the exposure to cosmic radiation of air crew for whom they are responsible. These studies should cover all rostering arrangements.

9.2 For operators of turbo-prop aircraft, predictions of dose, the maintenance of records of route dose rates, and individual air crew records of predicted dose may not be required because, owing to the normal flight characteristics of these aircraft, the annual doses of crew are likely to be low (less than 1mSv per year).

9.3 No controls are necessary for an individual member of air crew whose annual dose can be shown to be less than 1 mSv. Drawing on the measurements and evaluation of the EU research programme [4,5,6,7] , for flights at temperate latitudes at a typical altitude of 10.6 km (35,000 ft), and for average solar activity, the effective dose rate is about 5 to 6 microSv h-1, and therefore a total time at altitude of about 200 hours is needed to accumulate 1 mSv. Near the equator at this altitude, the time needed is about 400 hours. At an altitude of 11.8 km (39,000 ft) these times are about 150 and 300 hours respectively, and at an altitude of 10 km (33,000 ft), about 250 and 500 hours respectively.

9.4 Airlines generally work in terms of 'block hours'. These start from when the aircraft is pushed back from its stand and finish when its engines are switched off after landing. Block hours may therefore be considerably greater than flying hours, and this must be recognised when estimating doses.

9.5 Operators whose air crew may receive an effective dose greater than 1 mSv, generally those operators whose aircraft operate above 8km (26 000ft), should carry out an assessment, by computer program prediction, of the maximum annual dose to which their air crew are liable. The detail of these assessments of exposure, expressed in millisieverts per year, must be recorded [8] . If the assessed annual dose is less than 6mSv per year, the Directive does not require any further action to be taken. However, it should be noted that the European Commission guidance on this issue recommends individual monitoring. This is also common practice for ground-based workers with annual doses between 1 and 6 mSv.

9.6 Individual monitoring is to be regarded as best practise but it is recognised that this can impose unjustifiable cost for some operators. In these circumstances an acceptable course of action would be to rely on an assessment of maximum doses where this shows that air crew will not be approaching annual doses of 6 mSv. A suitable cut off point would be where the assessment indicates a maximum annual dose of 4 mSv. Where air crew are liable to receive doses in excess of 4 mSv per annum, it is recommended that there should be monitoring of individual air crew member's exposure using computer program prediction. The purpose of such monitoring would be to ensure that annual doses did not exceed 6 mSv.

9.7 Where an assessment of maximum doses indicates that air crew are liable to excede 6 mSv per annum, individual monitoring must be carried out. In addition, operators should adjust an air crew member's roster to reduce exposure with the aim of preventing, where possible, doses in excess of 6 mSv per annum. Records for individuals exposed to more than 6 mSv per annum must be kept for a minimum of 30 years from the last annual exposure of more than 6 mSv (even if the individual concerned is deceased) or until the individual is 75 years of age, whichever is the longer period of time.

9.8 Where the assessment of individual doses is necessary, this may be done by combining roster information with route doses. For example, a flight from northern Europe to the eastern seaboard of the USA will result in a value of effective dose of about 30 to 40 microSv. For a longer flight from northern Europe to Japan, the total effective dose is about 50 to 70 microSv. Transatlantic flights at the altitudes used by supersonic aircraft may give similar total effective doses as in subsonic aircraft, the higher dose rates being offset by the shorter flight times.

9.9 Unusually high levels of cosmic radiation at altitudes relevant to civil aviation can result from solar particle events (SPEs). These are produced by sudden, sporadic releases of energy in the solar atmosphere (solar flares), and by coronal mass ejections (CMEs). Only a small fraction of SPEs , a few per year, cause an observable increased intensity of cosmic radiation fields at aviation altitudes. These can be detected by ground monitors and are referred to as ground level events (GLEs). The largest events often take place on either side of the period of maximum solar activity as measured by sunspot number. Any rise in dose rates associated with an event is quite rapid, usually taking place in minutes. The duration may be hours to several days. The prediction of which events will give rise to significant increases in dose rates at aircraft altitudes is not currently possible. In the event of a rare SPE producing significantly elevated dose rates at aircraft altitudes it has been proposed that calculation of doses to crew on subsonic aircraft may be done retrospectively using computer calculations. However such a technique would require data from a large number of geomagnetically-dispersed, ground-level neutron monitors, and such calculations would require validation against flight observations using active monitors. Very few such observations have been made to date as only Concorde has had a regulatory requirement to carry a monitor. Information that a GLE has occurred will be made available to airlines and a summary of assessments of doses made available.

10. Monitoring Compliance

10.1 The operator should have a system of record keeping which should be detailed in the Operations Manual and which should be available for inspection by the CAA. The style of record to be kept will be offered in due course and is likely to be similar to that being proposed for JAR-OPS.

10.2 To facilitate using flight time and duty rosters for the maintenance of radiation records, and to give a more accurate record of dose received, the ANO requirements relate to a rolling year. This defines the year of record as being the period of 12 months expiring at the end of the previous month and accords with one of the definitions in the ANO with regard to flight time limitation records.

10.3 Similarly, the radiation records should be kept for a 12 month period after the last complete 12 month period recorded, i.e. for two years. This accords with the requirement to keep flight time limitation records for one year after the flight referred to. However, individuals exposed to more than 6mSv in any 12 month period must have their records kept for 30 years (even if the person is deceased), or until the individual reaches 75 years, whichever is the longer period of time.

10.4 Individuals are entitled to have access to their records and to be able to obtain a copy to offer their new employer, should they change employment.

11. Obtaining Further Advice

Advice may be obtained from the following sources:

Dr Robert Hunter
Civil Aviation Authority
Medical Division
Aviation House
Gatwick Airport
West Sussex
RH6 0YR

Website http://www.caa.co.uk/srg/med/default.asp
E mail cr@srg.caa.co.uk

Dr David Bartlett
Physical Dosimetry Department
National Radiological Protection Board
Chilton
Didcot
Oxon
OX11 ORQ

Tel: 01235 822728
Email david.bartlett@nrpb.org

Duncan Nicholls
Multilateral Division
Department for Transport
Zone 1/27
Great Minster House
76 Marsham Street
London
SW1P 4DR

Tel: 020 7944 6377
E-mail: duncan.nicholls@dft.gsi.gov.uk

For diskette versions of the CARI program, contact:

National Technical Information Service
5285 Port Royal Road
Springfield
VA22151

USA
Tel: 1-800-553-6847

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1. Council Directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for protection of the health of workers and the general public against the dangers arising from ionising radiation. Official Journal of the European Communities 39, L159. 29 June 1996.
2. International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Pergamon Press, Oxford, 1991.
3. European Commission Report. Radiation Protection 88.
4. European Radiation Dosimetry Group. Exposure of Air Crew to Cosmic Radiation. A Report of EURADOS Working Group 11. EURADOS Report 1996.01. European Commission Report Radiation Protection 85. Edited by I R McAulay, D T Bartlett, G Dietze, H G Menzel, K Schnuer and U J Schrewe. European Communities, Luxembourg, 1996.
5. O'Sullivan, D. coordinator, Study of Radiation Fields and Dosimetry at Aviation Altitudes, DIAS Report F14P-CT950011. Dublin Institute for Advanced Studies, Dublin, 1999.
6. Schrewe U J. ACREM, Air Crew Radiation Exposure Monitoring. Results from the in-flight measurement programme of the PTB: Summary of the radiation monitoring data, PTB Report PTB-6.31-99-1 (Physikolisch-Technische Bundesanstalt: Braunschweig) (1999).
7. Bartlett D T, Grillmaier R, Heinrich W, Lindborg L, O'Sullivan D, Schraube H, Silari M, and Tommasino L. The Cosmic Radiation Exposure of Aircraft Crew, Radiation Research. (1999).
8. Air Navigation (Cosmic Radiation) (Keeping of Records) Regulations 2000 [SI 2000/1380]