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Hoofdredacteur Mr C. Steinkhuler Rédacteur en chef
Rue de la Station 15
B- 1325 Longueville

Redactiesecretariaat Mme Cl. Stiévenart Secrétaire de Rédaction
Av. Armand Huysmans 206, bte 10
B- 1050 Bruxelles - Brussel

Dosimetrie van vliegend personefel
Dosimétrie du personnel navigant

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Dosimétrie du personnel navigant

SOMMAIRE INHOUD

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ASSESSING EXPOSURE TO COSMIC RADIATION DURING LONG-HAUL FLIGHTS

J.F. Bottollier-Depois

Institute for Protection and Nuclear Safety, BP 6,
92265 Fontenay-aux-Roses, France

ABSTRACT :

The assessment of exposure to cosmic radiation on board aircraft is one of the preoccupations of organisations responsible for radiation protection. Cosmic particles flux increases with altitude and latitude and depends on the solar activity. The exposure has been estimated on several airlines using transatlantic, Siberian and transequatorial routes on board subsonic and supersonic aircraft, to illustrate the effect of these parameters. Measurements have been realised with a tissue equivalent proportional counter; it's an adaptation of a system developed in collaboration with the CNES for space activities. Data have been collected at maximum solar activity in 1991-92 and at minimum in 1996-98. The lowest mean dose rate measured was 3 µSv.h^{-1} during a Paris-Buenos Aires flight in 1991; the highest was 6.6 µSv.h^{-1} during a Paris-Tokyo flight using a Siberian route and 9.7 µSv.h^{-1} on Concorde in 1996-97. The mean quality factor is around 1.8. The corresponding annual effective dose, based on 700 hours of flight for subsonic aircraft and 300 hours for Concorde, can be estimated between 2 mSv for least-exposed routes and 5 mSv for more exposed routes. An operational system (SIEVERT) is currently developed in France for airlines and the public to calculate the dose for a given flight.

1 - INTRODUCTION

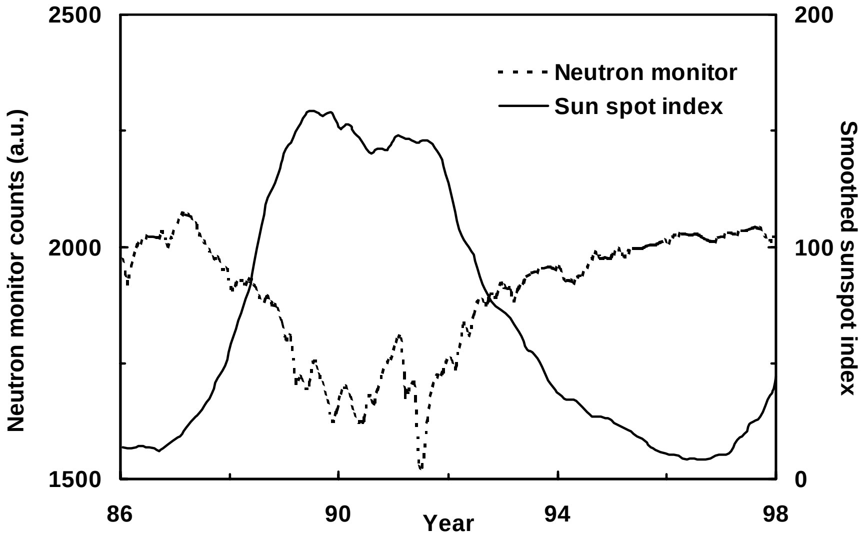
The study of naturally-occurring radiation and its effects on man is one of the preoccupations of organisations responsible for radiation protection. Space experiment programmes to assess the dose received by astronauts during a space mission have been supported for several decades. Some of the dosimetric systems developed for studies in space have been used to measure the doses received by flight crews on long-haul flights.

Cosmic particle flux increases with latitude and altitude. It is significantly higher on board aircraft than at ground level. The complexity of the radiation field does not make dose measurement easy. Indeed, the particles encountered vary considerably and a wide range of energies and types of particle are found. The gravity of the consequences for biological structures depends on the energy. Therefore, if the effective dose is to be estimated, the absorbed dose has to be known, along with the radiation weighting factor.

Several airlines were selected to illustrate the effect of parameters such as altitude, latitude and flight time. Measurements were planned for different periods of the year so that the effects of solar activity can be assessed. This study gives the results of measurements made during the 1996-98 period, when solar activity was at its lowest, on five routes out of Paris: Tokyo, San Francisco, Buenos Aires, Washington and New York (on Concorde). The results are compared to those obtained on three of these routes in 1991-92, when solar activity was at a peak.

2 - COSMIC RADIATION

The cosmic radiation on which radiation protection focuses is comprised at the outset of charged particles (ions and electrons) and secondary particles resulting from their interaction with the atmosphere (ions, neutrons, gamma rays, electrons etc.).
Primary cosmic radiation mainly consists of the nuclei of atoms which have lost their electrons due to their extremely high velocity. These charged particles are hydrogen nuclei (protons), helium nuclei (alpha particles) and the nuclei of heavier elements such as iron and nickel. One stable component is due to galactic and extra-galactic radiation; it comprises ions whose energy value can reach 10^{20} electronvolts, averaging out at a few 10^{9} electronvolts. The other component comes from the sun and is known as solar wind; it fluctuates with solar eruptions which produce large quantities of particles, mainly protons. Solar activity is varying with an 11-year cycle [Reit 93, Lant 93].
The charged particles move around and interact with the interstellar magnetic field and, for our purposes, with the terrestrial magnetic field to form the magnetosphere. At altitudes below a few earth radii (earth radius is 6370 km), the dipolar structure of the magnetic field predominates; this phenomenon explains the presence of polar cones centred around the magnetic poles where the magnetic field offers less resistance to incoming charged particles.
The particles making up the cosmic radiation also interact with interstellar gas and, closer to the earth, with the atmosphere. Secondary particles (neutrons, ions, electrons, gamma rays, muons etc.) are produced by interactions with atmospheric gas. A similar process occurs in aircraft skins. Because of the magnetic field and the atmosphere, only the most energetic ions, mainly those contained in galactic cosmic radiation, reach low altitudes. This galactic component is modulated by the solar wind outside the magnetosphere, being more heavily influenced when there is considerable solar activity. These phenomena explain why the flow of cosmic particles at ground level is lowest when solar activity is at a peak and vice versa. **Figure 1** illustrates solar activity and the changes in cosmic particle flux at ground level (Data provided by P. Lantos, Paris-Meudon Observatory). The magnetosphere and the atmosphere together form a powerful shield protecting us from cosmic rays. Without it, the dose received on the earth's surface would exceed 1 $Sv.year^{-1}$.



<u>Figure. 1:</u> Solar activity cycle (No. 22) given by the sun spot index and changes in cosmic radiation at ground level based on measurement of secondary neutrons (Kergelen station).

3 - MEASUREMENT APPARATUS

The device used to make the measurements, Nausicaa, was developed for space programs [Nguy 93]. One such instrument was used on board the Mir space station [Bott 96]. Portable versions are used in other situations, particularly aboard aircraft and in radiation facilities [Bott 97].
The detector is a Tissue Equivalent Proportional Counter (TEPC), considered by specialists as the reference detector for measuring doses from cosmic radiation [McAu 96]. It is sensitive to directly ionising particles (ions, electrons and gamma rays) as well as to neutrons via the charged secondary particles created by them in the walls of the counter. The sensitive volume is a 5 cm x 5 cm cylinder filled at low pressure (33 hPa) with a gas "equivalent" to biological tissue. This gas is based on propane: 50% C_3H_8, 40% CO_2 and 5% N_2. The detector simulates a 3 micron-long biological site located inside the organism at a depth of 1 cm.
Incident radiation produces electrons in the gas which are collected on the central anode, when an electric field is applied between the anode and the wall of the detector. Each event detected is analysed using a pulse height analysis method (PHA) and stored to produce the lineal energy distribution spectrum, d(y); y is the energy deposited divided by the average chord length of the detector. The system uses a logarithmic amplifier because of the dynamic range of y (10^4) and a 256 multi-channel analyser. There is a relationship between y and the linear energy transfer (LET) which is related to the quality factor (q(LET)). The sum of the deposited energy for each event divided by the mass of gas provides the absorbed dose (D), an assessment of the ambient dose equivalent (H*(10)) and the average quality factor (Q = H*(10)/D) of the radiation. An internal source of alpha particles (^{244}Cm) is used to adjust the high voltage of the system for calibration in terms of y. Calibration factors in terms of ambient dose equivalent are determined with a ^{60}Co source for LET lower than 4 keV/µm and with a AmBe neutron source for higher LET.

4 - RESULTS

The results given are those obtained from measurements made in 1996-98. They will be compared to the 1991-92 results [Nguy 92] to assess the effect of solar activity. Take-off and landing periods are taken into account when calculating doses received during flights and average dose rates. The ambient dose equivalent is calculated using the quality factor-LET relationship given in ICRP 60 [ICRP 91]. Since the irradiation of individuals is uniform, it is our opinion that the ambient dose equivalent value estimated by the measurements is a reasonable approximation, albeit overestimated at times, of the effective dose value. Moreover, since we are dealing with extremely penetrating radiation, the value of the average quality factor (Q) obtained from the experiment is a reasonable approximation of the mean radiation weighting factor, w_R.
Measurements, lasting 5 to 15 minutes, depending mainly on altitude, were made throughout all of the flights. The NAUSICAA device was installed in the flight deck on subsonic flights and in the cabin on Concorde. The Paris-Buenos Aires flight was not taken into consideration because certain measurements were affected by the aircraft instrumentation system. However data obtained during the return flight could be used for the outward trip since the two routes were comparable. The results obtained are presented taking into account the uncertainty arising from calibration and the statistical deviation for the average of measurements. The calibration uncertainty is estimated at 7% (one standard deviation). The statistical uncertainty about the mean ambient dose equivalent rate during a flight is lower than ± 10% corresponding to one standard deviation of the average value.
Figure 2 shows a map giving an overview of the ambient dose equivalent for the various flights during the period 1996-98. The maximum integrated dose, 150 µSv, is for the Paris-Tokyo round trip using a Siberian route and San Francisco. For Buenos Aires, the longest

flight, the dose is 30% lower (100 µSv). The dose received for the Paris-Washington round trip (14.6 hours) is comparable to that for New York with Concorde (7 hours). This comparison highlights the effect of altitude (up to 18,000 metres for Concorde). Figure 3 gives the ambient dose equivalent and the absorbed dose rate profiles measured for two flights and the effective dose rate calculated with the CARI-5E code [O'Bri 99], developed by the Federal Aviation Administration (USA). Dose rates increase with the flight level; this dependence is obvious for the absorbed dose rate. There are considerable local variations in ambient dose equivalent at times due to high LET events (> 10 keV.µm^{-1}) which have a significant effect in terms of dose but a lower probability of occurrence than low LET events. Dose distributions, d(y) and h(y), as a function of lineal energy (Fig. 4) show two distinct parts: the first, under 10 keV.µm^{-1} corresponds to low LET events, the second, above that level, is mainly due to secondary particles, i.e. protons and heavy ions, created by neutrons.

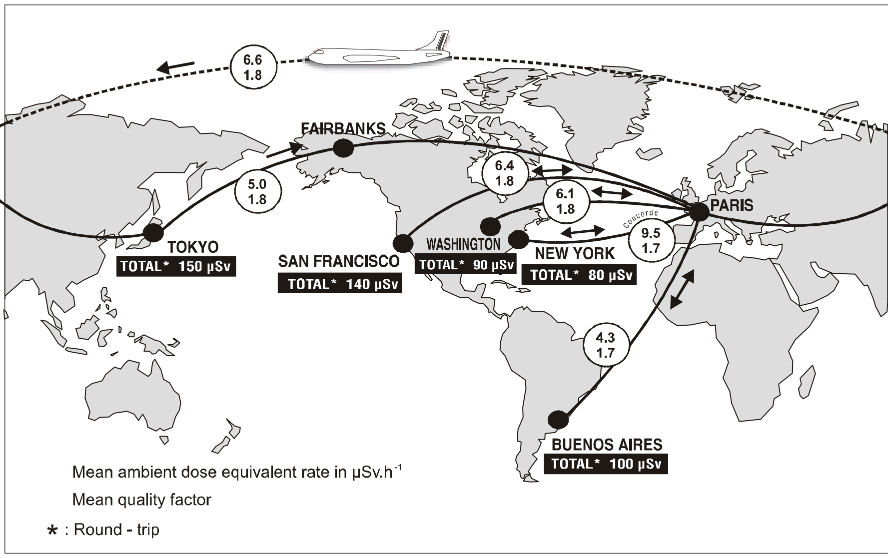


Figure. 2: *Route map for flights between 1996 and 1998 and the corresponding ambient dose equivalent rate, mean rate and cumulated over the flight and the mean quality factor*

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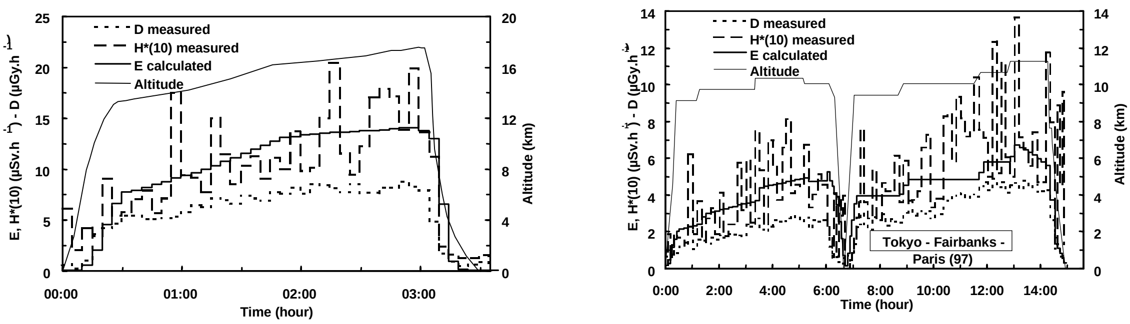
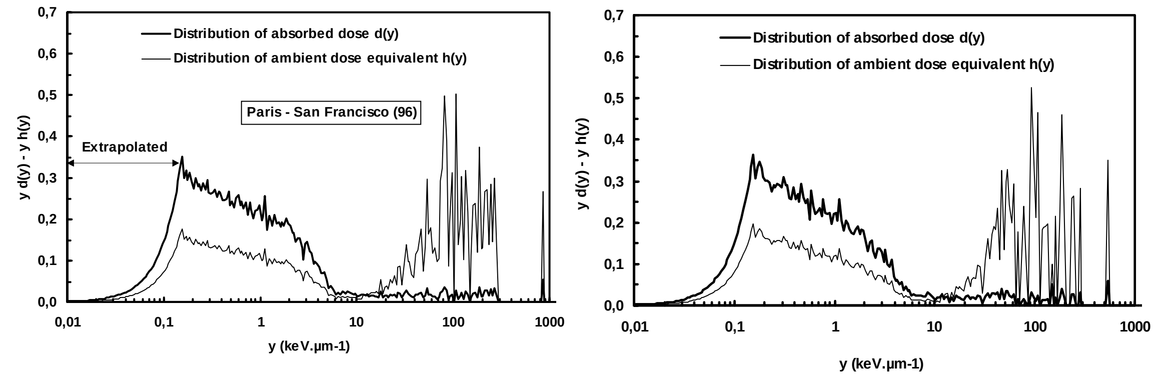


Fig. 3: *Profile of ambient dose equivalent rate (H*(10)), absorbed dose rate (D) and altitude for Paris-New York with Concorde (21/08/96) and Tokyo-Fairbanks-Paris with a cargo flight B747-200 (30/01/97). Comparison with the effective dose rate (E) calculated with the code CARI-5E.*



<u>Fig. 4:</u> Absorbed dose and ambient dose equivalent distribution as a function of lineal energy for Paris-San Francisco with a A340 (04/04/96) and Paris-New York with Concorde (21/08/96). The part above 10 keV/µm is mainly from neutrons.

Table 1 gives the flight parameters and the average dose rates obtained from measurements made in 1996-98. The high LET (above 10 keV.µm^{-1}) contribution estimated from the previous dose distributions can be assessed between 40% and 50% of the total ambient dose equivalent. The contribution of the neutron dose, included in the high LET part, is expected to increase at high latitude. Measurements performed by Schrewe [Schr 99] give a neutron dose fraction of 37% for geomagnetic latitudes below 30°N and 53% for those above 60°N. This effect is not evident mainly because the results represent the mean dose rates along routes starting from Paris which is located at a mid latitude (49°N). The mean quality factor is about 1.8 for a subsonic flight and 1.6 - 1.7 aboard Concorde. This variation is not significant given the uncertainties.

<u>Table 1:</u> Flight parameters and average dose rates obtained from measurements made in 1996-98.

Route and date	Flight duration (h)	Mean altitude (m)	Total dose equivalent rate (µSv.h^{-1})	Total absorbed dose rate (µGy.h^{-1})	High LET dose equivalent part (%)	Mean quality factor
Paris-Tokyo (Siberian route) (B747-400) 27/01/97	11.5	10700	6.6 ± 0.8	3.6 ± 0.4	45 ± 8	1.8 ± 0.2
Tokyo-Fairbanks-Paris (Polar route) (Cargo B747-200) 30/01/97	14.9	10100	5.0 ± 0.6	2.7 ± 0.3	45 ± 8	1.8 ± 0.2
Paris-San Francisco (A340) 03/04/96	11.4	11100	6.4 ± 0.8	3.5 ± 0.4	45 ± 8	1.8 ± 0.2
San Francisco-Paris (A340) 04/04/96	10.8	10600	6.3 ± 0.8	3.5 ± 0.4	44 ± 8	1.8 ± 0.2
Paris-Washington (B747-400) 22/01/98	7.3	10200	6.1 ± 0.8	3.4 ± 0.4	45 ± 8	1.8 ± 0.2
Buenos Aires-Paris (A340) 13/04/96	12.3	10300	4.3 ± 1.2 [a]	2.5 ± 0.8	44 ± 12	1.7 ± 0.3
Paris-New York (Concorde) 21/08/96	3.6	15400	9.7 ± 1.5	5.8 ± 0.8	41 ± 8	1.7 ± 0.2
New York-Paris (Concorde) 22/08/96	3.4	15000	9.2 ± 1.3	5.7 ± 0.8	42 ± 8	1.6 ± 0.2

[a] *The measurement uncertainties are higher in this flight because of onboard perturbations.*

A comparison with the 1991-92 measurements is presented in **Table 2**. The difference observed in the mean ambient dose equivalent rate between the two periods is not exactly that expected, especially for two routes. This is mainly due to the flight profiles. A difference of less than 2% is observed for Paris-Tokyo, against around 20% expected if we consider ground neutron monitor measurements **(see Fig. 1)**. The Paris-Tokyo data are given for a Paris-Tokyo flight in 1997 and Tokyo-Paris in 1992; these flights are not equivalent because of the magnetic rigidity which represents the ability of cosmic rays to penetrate the earth's magnetic field. For the Paris-Tokyo route, the cut-off rigidity is lower - 4 GV at Paris and 12 GV at Tokyo [Reit 93] - when the flight level is higher at the end of the flight, leading to an increase in the ambient dose equivalent of 18% in relation to a Paris-Tokyo flight. This effect has been assessed by calculation with CARI-5E using the actual flight parameters for the two routes at the same date. This difference is 40% for Buenos Aires-Paris against a few % expected at low latitudes [Reit 93]. The 1996 data have to be considered carefully because of measurement perturbations during the flight. Furthermore, the Buenos Aires-Paris flight was direct in 1996 but with an intermediate landing at Rio de Janeiro in 1992, giving a lower mean altitude and an underestimation of 10% (obtained by calculation) of the ambient dose equivalent relative to the 1996 flight profile. For Concorde, a 10% difference is observed, against more than 20% expected.

Table 2: Comparison of the 1996-98 measurements made during minimum solar activity with the 1991-92 measurements made during maximum solar activity.

Route	Mean ambient dose equivalent rate ($\mu Sv.h^{-1}$)					Mean altitude (m)	
	1991-92			1996-98		1991-92	1996-98
	real	Calculated [d]	corrected [e]	real	Calculated		
Paris-Tokyo (Siberian route)	6.5 ± 0.8 [a]	5.1	5.5 ± 0.8	6.6 ± 0.8	5.0	10700	10700
Buenos Aires-Paris	3.0 ± 0.5 [b]	2.8	3.2 ± 0.5	4.3 ± 1.2 [f]	3.0	10070	10300
Paris-New York (Concorde)	8.6 ± 1.3 [c]	7.9	8.5 ± 1.3	9.5 ± 1.4 [g]	8.8	15300	15200

[a] Mean value for the Tokyo-Paris flight (25/6/92).
[b] With an intermediate landing at Rio de Janeiro (6/5/92).
[c] Mean value of the Paris-New York flight (8/6/92).
[d] Calculated with CARI-5E using the actual route.
[e] Correction due to the difference in the flight profiles for each period. The corrected measured value is obtained using the 1996-98 flight profile as reference.
[f] The measurement uncertainties are higher in this flight because of onboard perturbations.
[g] Mean value for the two flights.

The annual ambient dose equivalent is estimated in the aircraft flying a particular route on the basis of 700 hours for subsonic flights and 300 hours for supersonic flights **(Table 3)**. These values are probably overestimated because the number of flight hours registered for each crew member is taken "block-block", time between departure from parking and arrival to parking.

Table 3: Annual dose equivalent in the aircraft flying a particular route, estimated on the basis of 700 hours for subsonic flights and 300 hours for supersonic flights during minimum and maximum solar activity.

Route	Annual dose equivalent (mSv)	
	1991-92 (corrected)	1996-98
Paris-Tokyo (Siberian route)	3.9 ± 0.2	4.6 ± 0.2
Paris-San Francisco-Paris	-	4.4 ± 0.3
Paris-Washington	-	4.3 ± 0.3
Buenos-Aires	2.3 ± 0.2	3.0 ± 0.4
Paris-New York (Concorde)	2.6 ± 0.5	2.8 ± 0.5

5 - DISCUSSION

As expected, the lowest average dose rates for long-haul flights are observed on routes close to the equator and when solar activity is at a peak (minimum amount of cosmic radiation at ground level). For example, in the 1991-92 period on the Paris-Buenos Aires flight, the average rate throughout the flight was around 3 $\mu Sv.h^{-1}$. The comparison of the 1991-92 ambient dose equivalent rates - corrected as described previously - with the 1996-98 ones, taking into account the statistical uncertainties, shows a fairly satisfactory agreement with the expected values.

At higher latitudes and when the solar activity is lower, the values are higher. For the Paris-Tokyo flight passing over Siberia, the average dose rate measured in 1997 was 6.6 $\mu Sv.h^{-1}$. The dose rate for a north Atlantic route is almost the same because the maximum latitude is comparable with that reached on a Siberian route. The cut-off rigidity is also lower. For the cargo flight between Tokyo and Paris passing over the North Pole, with a stop at Fairbanks, the average dose rate was 5 $\mu Sv.h^{-1}$. On polar routes at a given altitude, the cosmic radiation flux can generally be compared to that of Siberian routes. Indeed, beyond a geomagnetic latitude of 65°, it is taken as being constant. The measured value is lower than on Siberian routes because the average altitude is lower. As far as supersonic flights are concerned, the dose levels are far higher due to altitude (up to 18,000 metres). Throughout the Paris-New York flight during a period of low solar activity, the average rate was approximately 9.5 $\mu Sv.h^{-1}$. Agreement between the average experimental dose equivalent rate and the average effective dose rate given by CARI-5E is generally better than 20%, 30% for some flights, the experimental values being higher than the calculated ones.

For comparison, the equivalent dose rates for geomagnetic latitudes above 50°N, as a function of flight altitude between 9 and 13 km, - obtained from measurements made in 1996-98 **(Fig. 5)** - are coherent with those given by G. Reitz [Reit 93] for minimum solar activity and those obtained by Schrewe's measurements obtained with an ionisation chamber and a REM counter [Schr 99]. They are higher than those published by R. Regulla [Regu 93] and those calculated by CARI-5E by about 20% maximum. A comparison with results obtained with other TEPC's on flights between Europe and USA shows that the equivalent dose rate measured agrees within ± 20% [Lind 99].

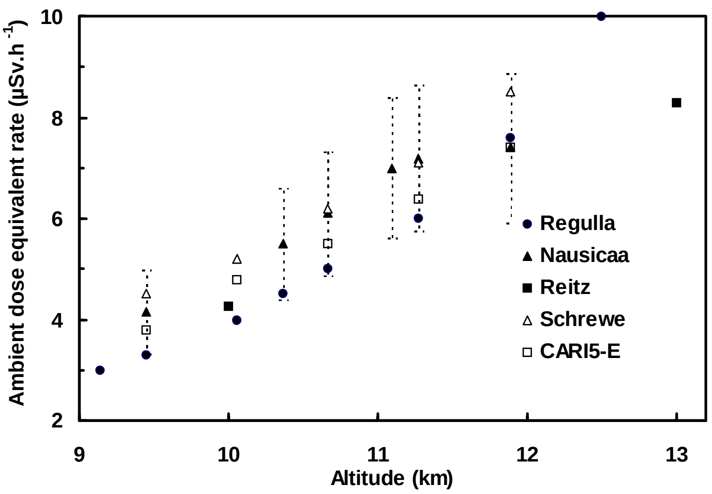


Fig. 5: Comparison of the ambient dose equivalent rates as a function of flight altitude, using the Q function according to ICRP60, for geomagnetic latitudes above 50°N.

6 - CONCLUSION

Dose measurements taken on board during long-haul flights can be used to assess an annual effective dose equivalent range, based on 700 hours of flight: between 2 mSv for the least-exposed long-haul flights at low latitude and during maximum solar activity (e.g. the flight to Buenos Aires) and should not exceeded 5 mSv for more-exposed routes at high latitude and with minimum solar activity (e.g. Paris-Tokyo by Siberian or polar route or Paris-San Francisco). The value on board Concorde falls within this range since the annual number of flight hours is lower (300 hours).
These values are clearly above the limits recommended for the public (1 $mSv.year^{-1}$) by the ICRP in 1991. For European countries, the Directive of 13 May 1996 [Euro 96] sets basic standards and rules to protect the health of the public and workers from the dangers of ionising radiation on the basis of ICRP recommendations. The Directive asks operating organisations to assess flight crew exposure whenever it exceeds 1 $mSv.year^{-1}$. Doses received by each crew member should be recorded for each flight and summed over a year and more. Using the appropriate computer programme and data file, personal exposure could be assessed if the various routes taken by individuals were known, along with the corresponding dates. An operational system, SIEVERT (Système d'Information et d'Evaluation par Vol de l'Exposition au Rayonnement cosmique dans les Transports aériens), is developed on behalf of the French Aviation Administration (DGAC), Institute for Nuclear Protection and Safety (IPSN) and Paris Observatory. The flight plan of each flight is sent by the companies and the server, operated by IPSN, returns the effective dose for the flight, computed using a world 3-D cartography of effective dose rates. Then the companies attribute the calculated dose to the file of each crew member. In case of important solar flare, the calculation will be postponed until time dependent cartographies become available for the ground level event time interval.

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Cancer risk of pilots and cabin crew – current epidemiology

Hajo Zeeb & Maria Blettner
Department of Epidemiology and Medical Statistics
Faculty of Public Health, University of Bielefeld, D-33501 Bielefeld, Germany

ABSTRACT

Pilots and cabin crew are exposed to natural cosmic radiation at their workplace and are now considered as occupationally exposed to ionising radiation. Until recently model calculations were the only way to assess the cancer risk of pilots and cabin crew. Direct observations were based on a small number of epidemiologic studies. From the viewpoint of radiation protection the large neutron contribution to the effective dose as a special feature of cosmic radiation is of importance.
A retrospective cohort study in 9 European countries is ongoing and will be analyzed in 2001. In Germany all pilots and crew employed 1960 or later (up to 1998) by Lufthansa and LTU were included in the cohort. Individual radiation exposure is estimated based on job histories and flight information combined in a job-exposure matrix. For both the European and the German data set we compare mortality of pilots and cabin crew in SMR analyses and investigate dose-response models using various measures of exposure.
So far, results from some incidence studies from Nordic countries participating in the European study are available. Consistently raised risks have been found for melanoma, some other sites showed increased rates in individual studies. The German study includes some 6236 pilots and 20896 cabin crew and allowed detailed investigations of individual radiation exposures. Results will be available towards the end of 2001
Large international studies are most useful to investigate the cancer risk of flight personnel. The results expected from the ongoing studies are important for the evaluation not only of health risks from radiation, but also of other occupational risks in pilots and cabin attendants.

1. INTRODUCTION

Pilots and cabin crew are exposed to cosmic radiation which consists primarily of high-LET (linear energy transfer) neutrons and low-LET gamma-rays. Levels of cosmic radiation increase with altitude because the shielding effects of the Earth's atmosphere decrease. Levels also vary with latitude, being highest near the poles where the terrestrial magnetic field provides less shielding. Solar flares are another source of radiation exposure and, although rare, solar events can be associated with a high-exposure rate.
In 1991 the International Commission on Radiological Protection (ICRP) recommended that natural sources of radiation should be regarded as occupational exposures for aircrew. The level of occupational exposure should be limited to a maximum of 20mSv (milli-Sievert) per year. For the general population it was recommended to lower

exposures to 1 mSv per year in excess of the background radiation from natural and technical sources which amounts to approximately 2.5 mSv per year. These recommendations have since been implemented in Europe.

The ICRP recommendations initiated discussions on regulating and monitoring exposure and on possible health impacts of the radiation exposure for flight personnel. It was calculated that at the typical altitude for commercial aircraft the cosmic radiation doses are about 5 to 8 micro Sv per hour (at 30,000 – 40,000 feet) and 12-20 micro Sv per hour on the Concorde. For frequent flyers, it some 200 flight hours per year would be necessary to exceed the annual 1 mSv limit. Despite some remaining uncertainties in accurately estimating the exposure to aircrew, the available programmes for dose estimation agree to a great extent (*see also the paper by Botellier in this issue*). Flying between e.g. Los Angeles and Frankfurt for 700 hours – a typical annual number of flight hours of aircrew – is likely to yield a cumulative annual dose in the range of 4.5 – 4.7 mSv. Flying the same amount of hours between Frankfurt and Lagos (Nigeria) results in approx. 1.5 mSv per year. Overall some aircrew members may receive between 4 and 6 mSv per year, and many receive lower doses. Flying for 20 to 30 years thus might result in a cumulative career dose of 80 to 180 mSv.

One approach to assess the cancer risk associated with this radiation exposure is to use estimates from radiation epidemiological studies among survivors from the atomic bomb in Hiroshima and Nagasaki. However, in recent years epidemiologic research teams worldwide have attempted to extend the scientific base for the assessment of health effects of low level radiation beyond the extrapolation from observations among atomic bomb survivors

2. EPIDEMIOLOGICAL STUDIES AMONG PILOTS AND CABIN CREW – METHODOLOGICAL CONSIDERATIONS

Observational epidemiologic research among aircrew is challenging because of the potential for bias and confounding and the play of chance. Pilots and cabin crew differ markedly from the general population with regard to lifestyle and socio-economic status. Thus, potential differences in disease risk might be related to health screening behaviour and recreational exposures rather than to specific occupational hazards. Among women delayed childbirth or low parity may influence, among others, the risk for cancers of the reproductive system.

Potential confounders in any epidemiological study might be air pollutants such as environmental tobacco smoke [1] which could reach high levels on long distance flights before smoking was banned on most flights. The potential health effects for flight crew of engine fuel combustion products [2], ozone [3] and electromagnetic fields are still unclear and under study [4]. Furthermore, effects of circadian rhythm changes such as sleep and menstrual cycle disturbances still warrant further evaluation.

From a statistical point of view, the low power to detect an increase risk related to the radiation exposure is a major challenge for epidemiological investigations. Therefore, large numbers of persons need to be included in studies in order to attain informative results. Additionally, the accurate measurement of the neutron contribution to dose equivalent of cosmic radiation has proven difficult, but the cumulative exposure appears to be relatively low and the range rather narrow. Based on linear extrapolations from studies of atomic bomb survivors the relative risk for solid cancers would be in the order of 1.06 for 100 mSv [5]. It is difficult to detect such a low risk with epidemiologic methods, particularly when confounding factors are present. In this situation, large cohort studies preferably combined in pooled analyses are probably the only option to increase the knowledge base. Additionally, results of direct observations need to be compared with model-based estimates obtained from investigations in population exposed to high levels of radiation. Since flight crew is perhaps the only occupational group regularly exposed to considerable levels of neutron radiation, research along the above lines may also contribute important points to the ongoing controversy about the radiation weighting factors for neutrons.

3. OVERVIEW OF STUDY RESULTS AMONG FLIGHT PERSONNEL

Several epidemiological studies among pilots have been published. Up to 1999, there were two reports on proportional mortality ratios (PMR) among pilots [6,7] one registry-based study on occupation and malignant melanoma [8], three cohort studies among civil pilots [9] and one cohort study among cabin crew [12]. Furthermore, a cohort study among members of the US Air Force [13] and a set of case-control studies on brain tumour [14,15] in this group were performed. We have previously reviewed these studies in detail [16].

The two PMR studies reported an increased risk of aircraft accidence and a slightly elevated PMR for all cancer. However, PMRs for circulatory and respiratory disease were noticeably decreased which in turn could have led to a higher proportion of cancer deaths. Two cohort mortality studies comparing pilots to the general population were performed in Canada (CP Air and Air Canada). Skin cancers were slightly increased in both studies, and a slight increase for several, but different other cancer sites was observed. The cohort study from Japan included only 59 deceased persons and yielded no information on site specific cancer deaths. In the United States Airforce aircrew cohort study among 200,000 persons, an increased overall cancer risk (Relative Risk RR = 1.31; 95% Confidence interval CI = 1.22-1.44) was found for flying officers as compared to non-flying officers. In this cohort a nested case-control study on brain tumours was carried out in which a significantly increased odds ratio (OR) for exposure to low frequency electromagnetic fields (OR=1.28; 95%CI 0.95-1.74) and to radiofrequency/microwave fields (OR=1.39; 95%CI 1.01-1.90) but no association of brain tumours with exposure to ionising radiation was seen (OR = 0.56; 95%CI 0.22-1.52.)

In Finland 1577 female and 187 male cabin crew were included in a cohort study from which a significant excess of breast cancer (Standardised Incidence Ratio SIR = 1.87; 95%CI 1.15-2.23) among female employees (most prominent 15 years after recruitment) was reported, sparking considerable discussion. Radiation doses of cabin attendants were judged to be too small to account for the observed excess risk. The potential confounding influences of reproductive factors such as late first birth and low parity could, however, not be evaluated in detail.

4. RECENT AND ONGOING STUDIES IN EUROPE

In Europe, new studies in 9 countries are currently in their final phase or already completed. Irvine at al published new results from their British Airways cohort in 1999, showing an excess risk of melanoma and some non- significant increases for brain and prostate cancers. National cohort studies of incident cancers have been performed in the

Nordic countries. So far, results from Denmark [17], Iceland [18,19] and Norway [20] have been published **(see Table 1)**.

Table 1: New incidence studies from Nordic countries: Pilots only

	Haldorsen et al., 2000		*Rafnsson et al., 2000*		*Gundestrup & Storm, 1999*	
Pilots licensed in	**Norway**		**Iceland**		**Denmark**	
Study period	**1946-1994**		**1955-1997**		**1946-1995**	
No. of persons	**3701**		**458**		**3877**	
Cancer	**Cases**	**SIR**	**Cases**	**SIR**	**Cases #**	**SIR**
All	200	1,06	23	0,97	92	1,2*
Rectum	9	0,9			1	0,3
Colon	16	1,1	1	0,64	4	0,8
Brain	9	1,1	2	1,75	2	0,6
Lung	25	1,0	2	0,64	-	-
All Leukaemia	2	0,5	1	1,69	5	2,4
Prostate	25	1,0	5	1,28	3	0,8
Melanoma	22	1,8*	5	10,2*	7	2,5*

SIR = standardised incidence ratio
 # only jet pilots
** statistically significant based on the 95% confidence interval*

The Danish study included 3877 cockpit crew (61756 person-years) and used total flight hours as a surrogate measurement for occupational exposure to cosmic radiation Overall, there was a slight increase in standardised cancer incidence (SIR = 1.1; 95%CI 0.94-1.28) and an increase in leukemia among jet pilots. Additionally an increased risk was seen for melanoma. The Norwegian study included 3701 pilots with a total of 70560 person years. In total, 200 cancer cases were reported (SIR = 1.06; 95%CI 0.92-1.22). Significantly increased risks were reported for melanoma (22 cases, SIR = 1.8; 95%CI 1.1-2.7) and for non-melanoma skin cancer. Similar results including an elevated melanoma risk (SIR=10.20, 95%CI 3.29-23.81) were reported from Iceland, both for pilots and for cabin crew. As in Finland, female cabin attendants had an increased breast cancer risk which was focussed in the cabin crew flying jets over an extended period of time.
The German cohort study includes 6236 pilots and 20896 cabin crew yielding some 105 000 person years (py) for pilots and 250 000 py for cabin crew. 248 deaths among pilots and 309 among cabin staff have been registered; the statistical analysis is under way. In terms of exposure data, we were able to obtain detailed information on annual flight hours for more than 80% of the pilots. In a validation study we compared different approaches to exposure estimation. Initially, we developed a job-exposure-matrix (JEM) linking job history data with radiation dose estimates for typical flight schedules (based on CARI-5E software

calculations)(latest CARI version available under [21]). The median annual radiation dose ranged from 1 mSv/annum (mSv/a) for short-haul pilots to 2 mSv/a for long-haul pilots. We then compared several alternative methods of exposure estimation, ie. the JEM approach (as above) with an approach based on detailed log-book data and with estimates based on either cumulative annual flight hours or on employment periods only. The correlation between the estimates obtained by the various approaches analyzed was rather high, ranging from 0.85 to 0.97. The precision attainable in the exposure assessment is thus higher than in many other epidemiological studies and we have some evidence that even basic information on employment periods can serve as a useful estimate of cosmic radiation exposure [22].

Several European countries including Greece, Italy, the UK and the Nordic countries as well as Germany have carried out cohort mortality studies under a common framework **(see Table 2)**

Table 2: ESCAPE - European Study of Cancer Risk among Airline Pilots and Cabin Crew

Country	Start of study period	Pilots	Cabin	Incidence*	Mortality*
Denmark	1946	3.885	6.070	X	x
Germany	1960	6.140	20.894		x
Finland	1967	799	1.693	X	x
Greece	1965	843	1.853		x
Iceland	1950	430	1.676	X	x
Italy	1965	3.026	6.845		x
Norway	1947	3.568	3.519	X	x
Sweden	1960	1.405	2.701	X	x
UK	1950	7580			x
EUROPE		**27.676**	**45.251**		

** x indicates that data are available*

. The development of a common study design and the pooled analysis of all data were facilitated through a EU sponsored research project (BIOMED 2 programme). Through the combined analysis the overall cohort will be the most powerful to date to evaluate late effects associated with occupation in airplane cockpits or cabins. The exposure assessment is based on occupational history data supplied by either companies or licensing agencies but is not available for all cohorts. In total approximately 73,000 aircrew are currently included in the Europe-wide study and results will be published in late 2001.

Epidemiological knowledge about the health of aircrew should be substantially increased through this large European study. The current studies are expected to markedly enhance the evidence base for policy decisions on aspects of radiation protection, but also on other health issues in these occupational groups. Not least the crews themselves are particularly interested in the epidemiological assessment of their health and disease experience.

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European legislation on protection of air crew against cosmic radiation

Klaus Schnuer,
European Commission,
DG ENV.C.4 Radiation Protection Unit, L-2920 Luxembourg

ABSTRACT

Specific provisions on radiological protection of air crew against heath effects arising from osmic radiation have been laid down for the first time at EU level as part of the new Basic Safety Standards for the Health Protection of the General Public and Workers against the Dangers of Ionizing Radiation (Council Directive 96/29/Euratom of 13 May 1996). These provisions, focusing mainly on health protection and on radiological surveillance, are minimal legal requirements. Therefore the Directive leaves significant discretion to the Member States as regards actions to be taken for the transposition into national legislation.
Member States had to transpose these provisions into national law before 13 May 2000.
In the field of radiological protection of air crew further harmonisation of Community regulations on civil aviation safety will be needed. That is to obtain a high level of radiation protection for the air crew and to maintain fair competition under the EU common transport policy. This is particularly required for working instructions (operations manual) established under the EU Regulations dealing with operational instructions and safety requirements for obtaining the licences to operate aircrafts.

1. INTRODUCTION

The activities of the European Union in the field of radiation protection of workers and the general public are based on Chapter III of the Treaty establishing the European Atomic Energy Community, one of the Rome Treaties of 1957.
The Treaty obliges the Community to establish Basic Safety Standards (BSS) for the health protection of workers and the general public and ensure that they are applied. The first Directive was adopted in 1959 and has been revised regularly since then.
The most recent version of the BSS was adopted in May 1996 for transposition into national law by May 2000.
Based on the 1990 Recommendations of the International Commission on Radiological Protection ICRP specific provisions on the health protection of air crew against dangers arising from cosmic radiation have been laid down for the first time at EU level as part of this new Basic Safety Standards. These provisions have to be seen as minimum requirements and therefore the Directive leaves significant discretion to the Member States as regards the practical means to be taken for implementation.

Radiation protection of air crew is also incorporated into other European legislation regulating technical requirements as well as in regulations dealing with social and economical aspects within the civil aviation sector. In order to initiate an permanent dialogue between all parties involved, the European Council established in 1990 (Council Decision of 30 July 1990 90/449/EEC) the Joint Committee on Civil Aviation. The aim is to promote the dialogue and co-operation between the European Commission and the airline industry, the airports and employers' organisations. The deep interrelation between different European and world-wide civil aviation regulations leads to a need for further harmonisation of Community regulations on civil aviation safety including the field of protection against cosmic radiation. That is, to obtain a high level of radiation protection for air crew whilst maintaining fair competition under the EU common transport policy. This is particularly required for working instructions (operations manual) as well as for the implementation of a Union policy aimed at improving living and working conditions in the civil aviation sector. This includes practical measures to be taken for the routine assessment of personal radiation dose.

2. APPLICATION OF THE EU BASIC SAFETY STANDARDS ON RADIATION PROTECTION TO COSMIC RADIATION

- The Basic Safety Standards for the Health Protection of the General Public and Workers against the Dangers of Ionising Radiation are laid down by a new Council Directive 96/29/Euratom of 13 May 1996, replacing Directive 80/836/Euratom. This new Directive differs in several aspects from the earlier versions. Now, special provisions are laid down for the first time concerning exposure to natural radiation sources at the workplace. (Title VII of the Directive).

- Protection of air crew from cosmic radiation is specifically dealt with in Article 42 of Directive 96/29/Euratom. According to this article "Each Member State shall make arrangements for undertakings operating aircraft to take account of exposure to cosmic radiation of air crew who are liable to be subject to exposure to more than 1 mSv per year. The undertakings shall take appropriate measures, in particular:
  (1) to assess the exposure of the crew concerned,
  (2) to take into account the assessed exposure when organising working schedules with a view to reducing the doses of highly exposed air crew,
  (3) to inform the workers concerned of the health risks their work involves,
  (4) to apply Article 10 to female air crew."

3. THE TECHNICAL RECOMMENDATIONS FOR THE IMPLEMENTATION OF TITLE VII OF THE EUROPEAN BASIC SAFETY STANDARDS

- In order to assist the Member States in transposing the Directive, guidance has been provided in a Commission Communication published on 30 April 1998 (W C 193). The Communication refers to Technical Recommendations for the Implementation of Title VII of the European Basic Safety Standards concerning Significant Increase in Exposure due to Natural Radiation Sources (Radiation Protection 88, Luxembourg, 1997). These Recommendations were established by a working party of the group of experts established under the terms of Article 31 of the Euratom Treaty.

- The Basic Safety Standards Directive requires that Member States' national competent authorities should ensure that studies are carried out to assess the likely magnitude of the exposure of air crew to cosmic radiation. The air companies shall be responsible for the execution of these assessments. The Commission is aware of the possible difficulties arising from the fact that there are many different employment systems in practice world-wide. It is important to underline that air crew in the sense of the Directive is taken to mean both flight deck crew and cabin crew.

- Article 42 explains directly that no further controls are necessary for air crew whose annual dose can be shown to be less than 1 mSv in a year. Individual doses of air crew operating routinely in air craft with cruising altitudes of less than 8000m are unlikely exceed 1 mSv in a year.

4. OCCUPATIONAL EXPOSURE CONTROL: GENERAL CONSIDERATIONS

- Article 22 of the Basic Safety Standards Directive requires that employers are obliged to inform classified workers on the health risks their work involves. In particular female staff should know of the need to control doses during pregnancy and that their employer must be notified about pregnancy so that necessary dose control measures can be introduced.

- Further in the Directive, (Article 21) a distinction is drawn for monitoring and surveillance purposes between those exposed workers who are liable to receive a dose greater than 6 mSv in a year and other exposed workers. It therefore seems appropriate to adopt the same level of dose limits to identify highly exposed air crew in the sense of Article 42 (second indent). Most recent Commission-supported research results show that, taking into account current air crew working patterns, it seems highly unlikely that an annual individual dose of 10 mSv per year could be exceeded.

- The question of exceeding the new dose limits for occupationally exposed workers thus does not arise. It will normally be possible to adjust rostering so that no individual exceeds 6 mSv per year. However, for air crew whose annual dose is likely to exceed 6 mSv, record keeping in the sense of the Directive is recommended combined with appropriate medical surveillance. It would be unnecessary and unhelpful to declare supervised or controlled areas in aircraft.

5. CONTROL OF OCCUPATIONAL EXPOSURE IN HIGH ALTITUDE CRUISING AIRCRAFT

- Annex 6 to the Chicago Convention (Standards and Recommended Practices for the Operation of Aircraft) requires that aircraft intended to operate above 15 km should carry a continuously working in-flight active monitor to detect any significant short-term variation in radiation levels and indicating cumulative dose on the flight. Short-term variations may arise as a result of solar flares, which can cause a sharp increase in the solar component of primary cosmic radiation especially at very high altitudes. Potential exposure resulting from such a flare can be significantly reduced by a controlled descent if active monitoring is used. The galactic component of cosmic radiation, which is greater at lower altitudes is not subject to such sudden changes.

- Air crew operating aircraft in this high altitudes should be subject to the same general monitoring regime as air crew flying routinely between 8 and 15 km but account should be taken of the potential variability of doses. Active monitoring may be used to assess individual doses to which this particular air crew are exposed or simply to provide a warning of high dose rates. In the latter case, doses should be assessed using a technique, which takes account of the variability of the composition of the radiation environment above 15 km.

6. CONTROL OF OCCUPATIONAL EXPOSURE OF PREGNANT WOMEN

- It should be noted that the provisions of Article 10 apply to pregnant air crew and. once pregnancy is declared, the protection of the unborn child should be comparable with that provided for members of the public. This means that once the pregnancy is declared the employer must plan future exposures to control the dose to the foetus below 1 mSv either for the remainder of the pregnancy or for the whole pregnancy depending on how Article 10 is implemented in national legislation.

- In many circumstances in radiation protection, it can be assumed that the dose to the foetus will be below 1 mSv if the dose to the surface of the mother's abdomen is kept below 2 mSv. This is not the case when the dose is due to the penetrating cosmic radiation which delivers the dose during flying and the dose to the foetus will be effectively the same as that to the surface of the mother's abdomen. The provision of Article 10.2 in Directive 96/29/Euratom relating to nursing mothers is not relevant to external exposure from cosmic rays.

7. THE ENVISAGED APPLICATION OF AIR TRANSPORT LEGISLATION TO COSMIC RADIATION

- Exposure to cosmic radiation is presently regulated by the EU radiation protection legislation. The EU air transport legislation will also cover this issue in a near future.
  The Community Air Transport Policy had to address the harmonisation of the regulatory framework, applicable to civil aviation in order both to maintain a high level of safety and to ensure fair competition in the internal market.

- To achieve these goals Council Regulation EEC Nr.3922/91 was adopted on 16 December 1991 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation. The aim of this Regulation is to establish and keep up to date harmonised rules for the design, manufacture, operation and maintenance of aircraft and for personnel and organisations involved in these tasks. Additionally, this Council Regulation lists a number of technical requirements to be directly adopted, so-called "Joint Aviation Requirements (JARs)". They are produced by the Joint Aviation Authorities JAA, based on multinational agreements and conventions on the safety and security in the civil aviation sector: JARs Operational Procedures are given the force of law in the Community.

- The JAA is an associated body of the European Civil Aviation Conference (ECAC) through which arrangements to co-operate in the development and implementation of JARs in all fields relating to the safety of aircraft and their operation have been established.

- 'The Commission services examined the document adopted by the JAA in 1995 with the aim of establishing harmonised operational requirements for the operation of aircraft engaged in commercial air transportation: that is the carriage by air of passengers or cargo for remuneration or hire.

- As regards cosmic radiation the following requirements will be proposed by the Commission: OPS 1.390 Cosmic Radiation

a) an operator shall ensure that the national rules adopted for the transposition of the Council Directive 96/29/Euratom are complied with.
b) an operator shall not operate an aeroplane above 15 000 m (49 000 ft) unless the equipment specified in OPS 1.680 is serviceable.
c) a pilot-in-command shall initiate a descent as soon as practicable when the limit values specified in the Operations Manual are exceeded.

8. RADIATION PROTECTION OF FREQUENT FLYERS

- Frequent flyers are considered as a special group of workers using air transport execute their duties in different working areas such as escorting, maintenance or courier services. The Directive does not foresee a direct obligation for the Member States authorities to establish for this category of workers a system of radiological control and monitoring.

- However, legal coverage for this category of workers is indirectly foreseen by the BSS Directive. As mentioned above, Title VII obliges the Member States authorities to identify workplaces with enhanced levels of natural radiation witch cannot be disregarded from the radiation protection point of view. Due to the very complex and different work situations in the individual Member States, the Directive leaves considerable freedom for the identification of such special workplaces. This particular case of frequent flyers does not apply for all Member States. Therefore, it is the responsibility of the individual Member States authorities to initiate assessments with the aim of identifying whether this particular work activity needs measures to be taken in order to monitor exposure and to reduce doses.

  The Recommendations for the implementation of Title VII elaborated by the Expert Group under Article 31 of the Treaty mentions that the employers of such frequently flying workers should make arrangements for determining doses similar to those made by airlines for their staff.

9. EXPOSURE OF PASSENGERS TO COSMIC RADIATION

- As described earlier, the Directive lays down Basic Safety Standards for the protection of the workers and the general public. In the spirit of the Directive, air passengers are considered to be members of the general public.

- Article 2 defines that the Directive shall also apply to work activities other than described by the Article, if the presence of natural radiation sources leads to significant increase of exposure of both workers and general public, which cannot be disregarded from the radiation protection point of view. In this respect, the realistic dose assessment of passengers enables the determination of the radiological risk. The dose limit for members of the public resulting from an activity involving ionising radiation is 1mSv per year.

- Taking into account realistic flight situations one transatlantic crossing results in 25 micro Sv. Subsequently, 40 travels from Europe to the US are necessary to receive a dose of more than the limits as laid down by the Directive. Therefore it is rather unlikely that members of public are liable to receive radiation dose of more than 1 mSv in a year.

10. CONCLUSIONS

- In the course of their work, civil air crew and frequent flyers are exposed to elevated levels of natural background radiation, specifically cosmic radiation of galactic and solar origin and secondary radiation produced in the atmosphere and aircraft structure. This has been recognised for many years.
  The recent increased interest on the subject has been promoted by several factors. Firstly, there was the consideration that the relative biological effectiveness of neutron radiation was underestimated by the definition of the former dose quantities. Secondly, there are considerable developments in the design of aeroplanes leading to higher flight altitudes, longer non-stop flights and consequently also to heavier work load of operating air crew.

- The Article 31 expert group recommends that for regulatory dose assessment and recording purposes, estimates of either effective dose or personal equivalent dose may need to be required. The preferred procedure to estimate doses is to determine route doses and combine this with data on individual flight profiles. The route doses may be obtained from calculations of the radiation field as function of the composition of the radiation environment and solar cycle phase. Instrument measurements may be made in order to update the dose calculation parameters describing the radiation field.

- The Radiation Protection Unit is currently co-ordinating related research and regulatory work in order to provide the Member States' radiation protection authorities as well as the airline industry with a computer programme, which fulfils these requirements in a harmonised way.

- Dose estimation procedures may not be necessary for persons for whom total annual doses will not exceed 1 mSv and therefore, in particular, for air crew not routinely flying above 8 km altitude and for normal air passengers.