Cosmic radiation during air travel: trends in exposure for aircrews and airline passengers

R.O. Blaauboer
Laboratory for Radiation Research, National Institute for Public Health and the Environment,
P.O. Box 1, 3720 BA Bilthoven, The Netherlands.
E-mail: roelf.blaauboer@rivm.nl

Abstract. On the basis of a detailed survey on passengers arriving at or departing from Amsterdam Schiphol Airport in the 1988-1997 period, estimates of individual effective dose for specific destinations and the collective dose for all passengers travelling through Amsterdam Schiphol Airport in the Netherlands were calculated. A computer model was used to calculate flight profiles for various types of aircraft and flying distances. This was followed by calculations using the CARI model to determine the dose for each flight profile. Most of the flights were regional European flights, resulting in individual effective doses of 1-15 µSv. Individual effective doses from intercontinental flights to North America and the Far East were mostly found in the range of 30-60 µSv per flight. These values may vary up to ±15 % due to the solar cycle. The individual effective dose on a one-way flight averaged over all flights was approximately 18 µSv. A group consisting of 4000 frequent flyers may receive doses above 1 $mSv \cdot a^{-1}$, while within the special group of couriers individual effective doses of 10 mSv a^{-1} are possible. For aircrews, a dose range of 1.5-5.7 $mSv \cdot a^{-1}$ was determined for 1000 block hours of flying. The collective dose for passengers flying through Schiphol increased from 230 to 600 manSv from 1988 to 2002. The collective dose for aircrews comprises about 6% of this dose. If a moderate growth in air transport of 4% per year is assumed, the collective dose will reach 1100 manSv in 2015.

1. Introduction

In recent years interest has arisen on the subject of the radiation dose due to air travel, especially with reference to air crews. This interest may be explained by the use of aircraft types that fly more efficiently at higher altitudes, but also by changes in policy, for instance, European regulations [1] and their applications in national laws. For instance, a dose of 1 $mSv \cdot a^{-1}$ brings aircrews under radiation protection law and makes monitoring of individual doses mandatory. In the United States the emphasis is placed on informing aircrews, specifically pregnant crew members [2, 3]. The often marginal profits that are achieved in the industry are at odds with a temporary transfer of pregnant crew members to ground-based posts. New regulations therefore might affect working conditions. One other reason for the new interest in air travel is the reevaluation of the contribution made by the neutron component to the dose, giving this component more importance than assumed until recently [4].

In earlier work doses to aircrew and members of the general population were often estimated from much information on averages, for instance, flying distance and speed, dose rates at cruising altitudes, number of people departing or arriving at a national airport or even total number of people flying internationally [5].

Nowadays, more specific statistics on air travel are available and software that makes calculation of doses possible for every route imaginable is also readily obtainable. It is therefore now possible to make better estimates on doses received by both crew members and members of the general population.

2. Methods and data

An important part of the research was the collection of information, particularly statistics on aircraft movements, numbers of passengers travelling through Schiphol Airport, flight data and airport location data. These data are further discussed in the following sections. Based on these data flight levels were modelled for different aircraft types using a method by Oksanen [6] and calculations performed with the dose model CARI, version 6 [3]. All results, along with the most important input data, are included in a report available through the internet [7].

2.1. Numbers of passengers

To estimate the contribution to the collective effective dose of a flight to or from a specific location on earth, the number of passengers travelling on the flights have to be known. In the Netherlands the majority of all international flights, transporting some 40 million passengers in the 12 months previous to September 2001, connect to Schiphol Amsterdam Airport.

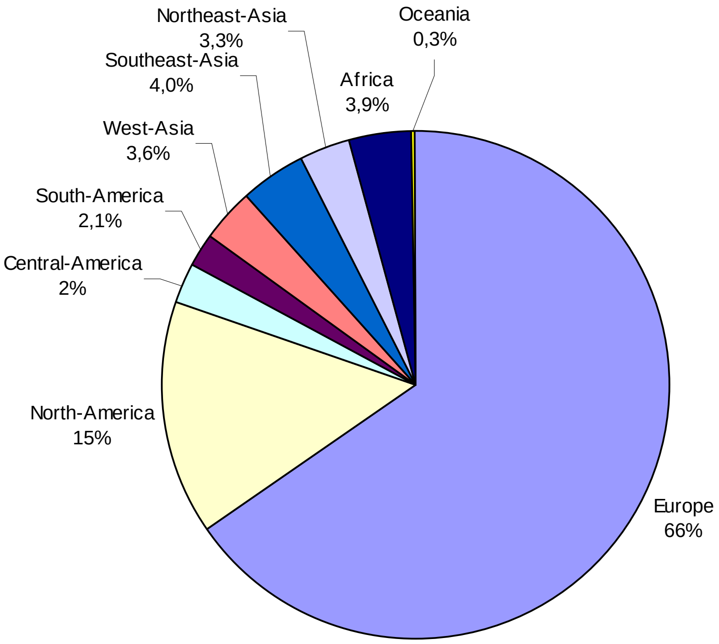

FIG.1. Departure from and arrival of passengers at Schiphol airport in 1997 [8].

Detailed information on departures and arrivals for 1988 through 1997 is available [8] through the Statistics Netherlands (CBS). Destination and departure points were compiled, along with the numbers of passengers. All destinations with at least 2000 passengers arriving and departing in a single year during this period were also included, resulting in a list of about 180 destinations for 1988, increasing to almost 240 in 1997, accounting for some 99% of all passengers. As can be seen in FIG. 1, most of the passengers passing through Schiphol Airport arrive from or are transferring to another European airport. This subdivides the passengers into one large group, on European flights, with relatively low doses, and a smaller group on intercontinental flights, associated with higher doses.

Although the total number of passengers increased considerably, the slices of the pie (percentages) in FIG. 1 did not expand during the 10-year period recorded (1988-1997). Because specific destination information was not (yet) available in the research period for 1998 to the present, figures were scaled using the total growth in passenger numbers.

Information from the CPB (Netherlands Bureau for Economic Policy Analysis) [9] and the ICAO (Intenational Civil Aviation Organization) [10] was used for figures on future aviation growth.

2.2. Aircraft movements and flight data

The total flight duration is an important parameter for obtaining the right flight profile (i.e. flight levels, flight duration, aircraft type, possible stopovers etc.). For instance, the required amount of fuel based on factors such as flight duration (depending on distance, weather and traffic) is calculated, and the optimal flight levels or vertical profile are planned for the type of aircraft concerned. Total flying times used here are taken from a number of sources (see [7] for references).

It is fairly difficult to obtain straightforward information on flight profiles. Pilots make use of different flying altitudes instead of cruising speed at one altitude only. The airplanes flying east make use of other flight levels than those flying west. For short distances pilots will more often fly at lower altitudes than for intercontinental flights. Different countries have different requirements on routes flown in their airspace. Furthermore, every type of aircraft has its optimum flying altitude, depending on weight and fuel consumption, which, in turn, again depends on distance flown. Weather conditions may have an impact on the flight profiles, just as wars fought down below. All these parameters lead to flight profiles that may differ considerably, even for trips to the same destination.

We can conclude here then that some reasonable choice will have to be made on how to define the flight profile from airport A to airport B.

Besides information on distance of the trip and type of aircraft, airport location data is needed for a proper calculation of the effective dose using the CARI model. These data, collected from various sources (see [7]) include airport code (using IATA or ICAO coding), geographical coordinates and height above sea level.

2.3. Flight level modelling

As mentioned earlier, it is fairly difficult to obtain straightforward information on flight profiles for all kinds of reasons. However, Oksanen [6] introduced a way to model these flight profiles for a number of aircraft types (i.e. DC9, DC10, MD11 and MD80, all McDonnell Douglas planes, and the Airbus A300). He made fits to the optimum flight levels using information from the so-called aircraft performance manuals of a number of aircraft types. A further description of this method may be found in the article by Oksanen and for the manner it was applied in the report mentioned earlier [7].

2.4. Dose calculation

The CARI computer model was used for calculating the effective dose due to galactic radiation, the major component of cosmic radiation on earth. This model, in use by pilots and other crew members through the Federal Aviation Administration (US-FAA), is available for calculations [11].
Applying the model, it is possible to calculate the effective dose for an individual during a flight. Monthly calculations are possible because of the availability of the heliocentric potential, as input parameter, on a monthly basis. The heliocentric potential is an interplanetary magnetic field index functioning as a measure of the solar activity. Although some variation occurs throughout the year, a yearly averaged value for the heliocentric potential is adequate for the modelling purposes (yearly dose and monthly data on air travel are not readily available) described here.

3. Results

Since the research was geared to dose-rate distributions for crews and passengers the results of the calculations have also been differentiated. Therefore separate results are given on dose rates for different destinations and an account of the consequences this has for the individual doses to aircrew and passengers and the collective doses of these groups. This is followed by a section on the trends in dose rates and collective dose as a result of the solar cycle and increase in air transport.

3.1. Dose rates and destinations

As one of the larger airports in the world, Schiphol is frequented by a large number of airlines that serve several hundred destinations worldwide. For all these destinations effective doses were calculated for a one-way trip, i.e. averaged over the outbound and return flights for 1988-1997.

In FIG. 2 effective dose rates are summarised for all destinations for two ‘extreme’ years during solar maxima and minima. Because most of the destinations are in Europe (within a few flying hours), climbing and descending are relatively important. Climbing and descending together take roughly one hour and only the flying time on cruising altitude determines the overall dose. Therefore, average dose rates on short distances will be highly affected by climbing and descending. Regional flights of up to one hour give dose rates up to 2 $\mu Sv \cdot h^{-1}$. Dose rates for continental flights of up to four hours are in the range 2 – 3.5 $\mu Sv \cdot h^{-1}$ in 1990 and 2.4 – 4.5 $\mu Sv \cdot h^{-1}$ in 1997, and intercontinental flights range from 2 – 4.3 $\mu Sv \cdot h^{-1}$ in 1990 to 2.4 – 5.7 $\mu Sv \cdot h^{-1}$ in 1997. These last two ranges depend heavily on the hemisphere the destination is in. For instance, calculated average dose rate for the almost 20-hour flight from Amsterdam to Sydney (Australia) is 2.8 $\mu Sv \cdot h^{-1}$ for 1997, while this is 5.6 $\mu Sv \cdot h^{-1}$ for the less-than-12-hour flight from Amsterdam to Calgary (Canada). All flights that pass the equator encounter this ‘low’ dose rate area.

Dose rates at high altitudes for supersonic flights (18 km) were in the range, 10 – 12 $\mu Sv \cdot h^{-1}$ during measurements from 1976-1983 and 1988-1990 [5]. However, by way of compensation, flights are shorter than at conventional altitudes (10-12 km) and aircrews generally fly fewer hours. Furthermore, supersonic flights are not scheduled at Schiphol and therefore will not be further considered.

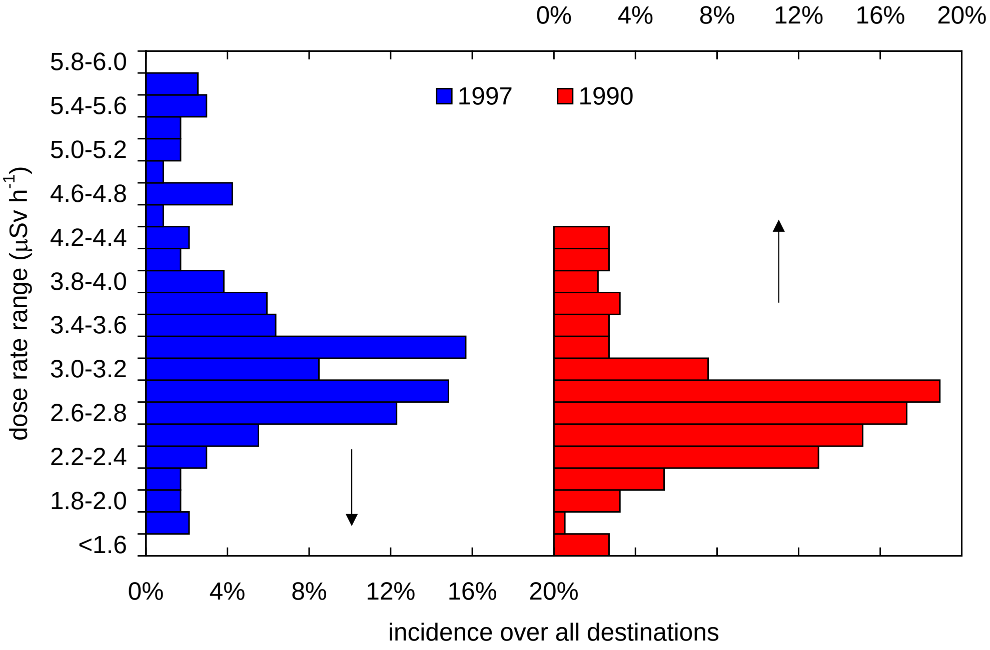

FIG. 2. Distribution of average effective dose rates over all destinations (not all flights!) reached from Schiphol Amsterdam Airport. The years shown are for maximum (1990) and minimum (1997) solar activity during the previous solar cycle. Dose rate intervals is 200 nSv·h^{-1}.

Most of the reasoning above also holds for the total dose during flights (FIG. 3). Regional flights (less than one hour) result in individual doses of 2 µSv at the most. For continental flights of up to four hours effective doses per one-way trip are 2 – 11 µSv for 1990 and 2.5 - 14 µSv for 1997. Doses for intercontinental flights range from 10 – 68 µSv for 1990 and 12 – 84 µSv for 1997.

3.2. Individual doses

The exposed population may be split into the professionally exposed group (aircrews) and passengers. The focus on aircrews is important because they receive relatively high doses, and because EU and national directives have been developed especially for this group.

3.2.1. Aircrews

For members of an aircrew, that is pilots, flight engineers and cabin crew, there are two important parameters: the number of flying hours or block hours (the time between removing the blocks from the aircraft and placing them again at the destination) per year and the specific flight schedules. It is clear that for local or regional flights, doses will not be as high as for intercontinental flights. Even average dose rates are lower because of the relative weight of climbing and landing in the total flying time. See also section 3.1.

Assuming yearly flight hours to be 1000 block hours for aircrews of commercial airlines, a dose range of 2 – 5.7 mSv·a^{-1} can be calculated as the individual dose in 1997 (extreme ranges in FIG. 2), depending on the routes flown from and to Amsterdam. However, it should be noted that 1997 was a year with a solar minimum. For 2002 this dose will range from about 1.5 – 4.7 mSv for the same number of block hours. This effect of the solar cycle is illustrated in FIG. 4 where the effective dose of a one-way flight from Amsterdam to Houston (Texas) is presented for a number of years.

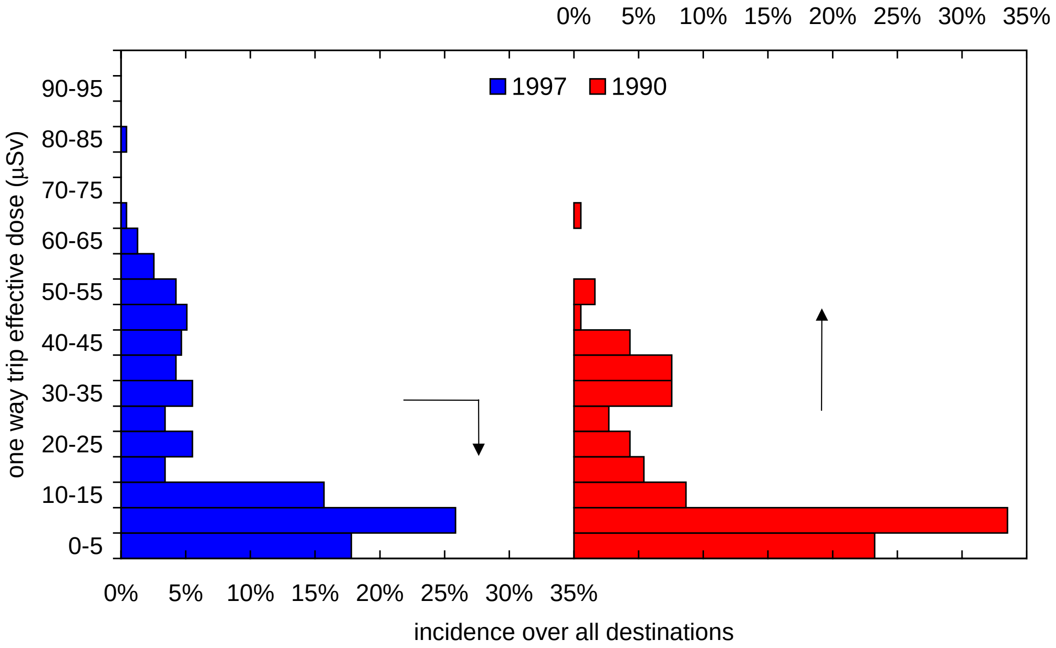

FIG. 3. *Distribution of average effective dose per one-way trip for all destinations (not all flights!) reached from Schiphol Amsterdam Airport. The years shown are for maximum (1990) and minimum (1997) solar activity during the previous solar cycle. Dose intervals is 5 µSv.*

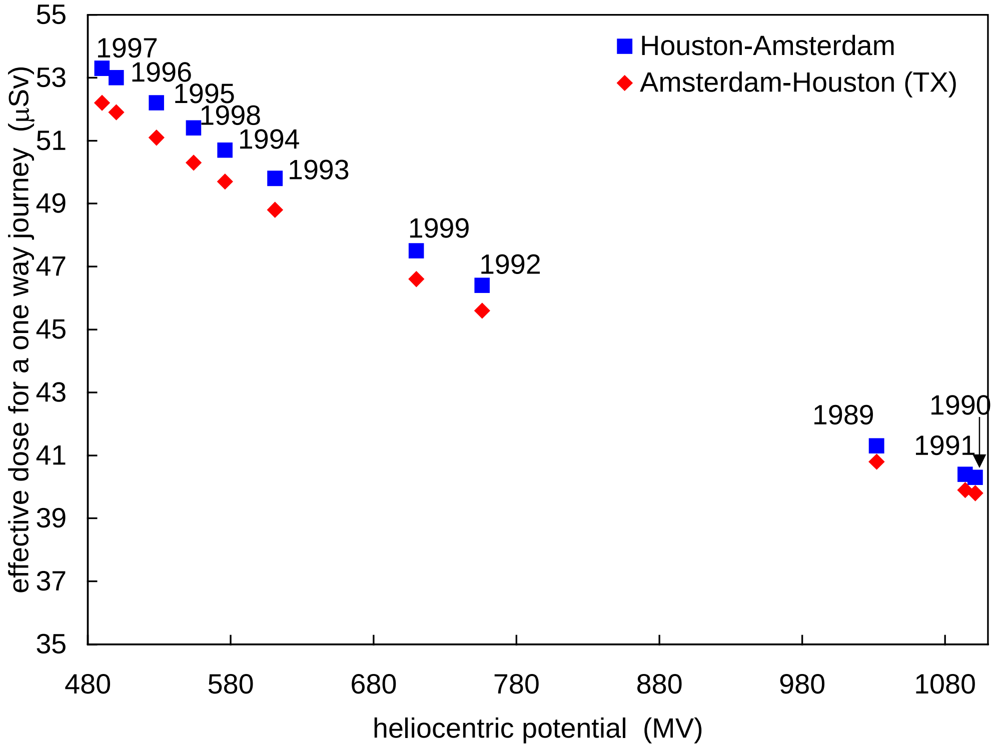

FIG. 4. *Effective dose for a one-way flight from Amsterdam to Houston and the other way around. The large differences between years are due to the solar cycle. The differences seen in between the different flight directions are caused by fuel consumption, generally making it more efficient for an aircraft to climb until the landing stage is set in. If the plane flies northward (in this case, Amsterdam) it will encounter higher dose rates at the end of the journey than when it goes southward (Houston).*

The actual dose received by airline personnel depends, of course, on the actual number of hours flown. This may be regulated by national law. Furthermore, aircrews flying on private (business) jets might receive doses that are somewhat higher because they are sometimes assigned flight levels above those of the commercial airlines. The more individually specific dose is calculated in the Netherlands for each flight using the computer generated flight plan and CARI. This information is stored for all crewmembers in the national dose register, NDRIS, for occupationally exposed workers.

3.2.2. Passengers

From the transport of passengers to the various destinations (FIG. 1), it is clear that many of the commercial flights in question are within Europe. Most of these flights take place over short distances and are in a temperate (dose-rate) region; this means that flight doses will be relatively low.

FIG. 5 presents the distribution of doses among all passengers. A significant percentage (ca. 70%) of all passengers, especially those travelling to European destinations, receives effective doses per flight of less than 15 µSv. Some 20% of them received doses in 1997 in the range of 40 – 60 µSv per flight.

These relatively high doses hold primarily for passengers flying to or from North America and East Asia. As best seen in the figure, there is a shift to lower doses during a period of maximum solar activity (around 1990).

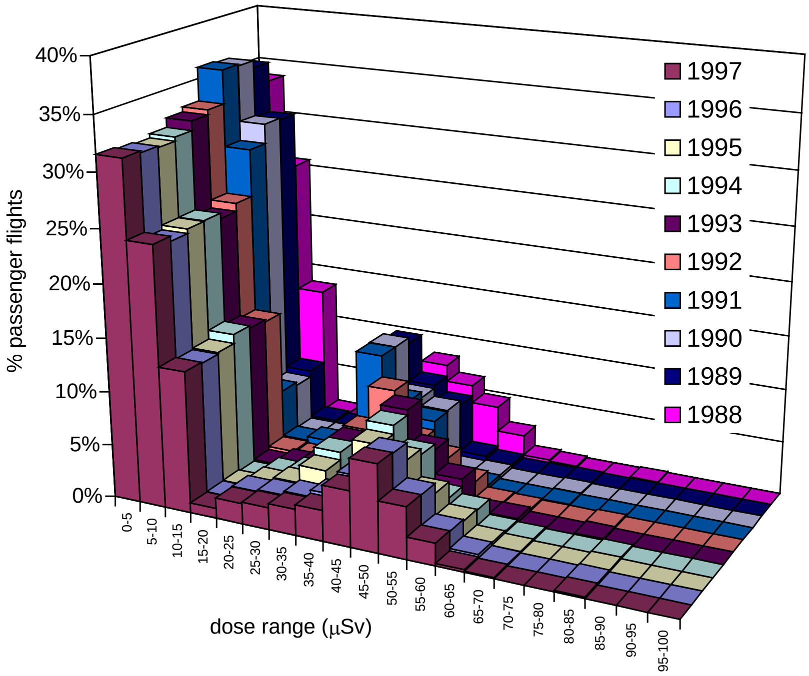

FIG. 5. Dose distributions over all passenger flights (one-way) between 1988 and 1997 from and to Schiphol Amsterdam Airport. Most of the passengers will also make a return trip and thereby double their dose.

Although most of the Dutch passengers encountered at Schiphol airport are flying more frequently, their total number is still lower than that of the passengers taking one trip. No information was available on the destinations of frequent flyers, but every month a return trip from Amsterdam to a city in North America is surely not an extreme case. In FIG. 4 it can be seen that these frequent flyers may easily receive annual doses of more than 1 mSv (expected range 0.15-1.5 mSv·a^{-1} and on average 0.5 mSv·a^{-1}). Most of these 83,000 (Dutch) frequent flyers probably stay within Europe for their business, as is the case for all passengers. In Germany, with five times as many inhabitants as the Netherlands, some 20,000 persons are expected to receive annual doses exceeding 1 mSv [5]. Although very uncertain, this would imply that some 4000 (Dutch) frequent flyers would exceed the 1 mSv per year.

With the increase of air travel, the group of business travellers, not under dosimetric control, will also increase. The European Commission has recognised this problem and recommended that although air couriers and other exceptionally frequent flyers are not mentioned in Article 42 of the Basic Safety Standards [1], ‘employers of such individuals should make arrangements for determining doses similar to those made by airlines for their staff’ [12].

3.3. Collective doses

Collective dose is a way of comparing more generally the dose implications of various exposures. For the occupationally exposed, this provides insight into the radiological effects of their work, and for the general population, it offers the opportunity to compare the risks of radiological exposures to those of various other agents.

3.3.1. Aircrew

Of all aircraft movements at Schiphol airport in 1999, about 45% were made by Dutch carriers. The collective dose for crew members on these carriers (about 11,000) in 2002 was estimated at 16 manSv [13]. The total collective dose for aircrews using the Amsterdam airport can then be estimated at about 36 manSv for 2002 or some 6% of the collective dose to passengers (see next section). Based on the number of passenger kilometres performed (3.7% of the worldwide performance in 1997 [14]) this amounts to about 1000 manSv for aircrews worldwide in 2002. UNSCEAR estimated 800 manSv for the year 2000 [5].

The collective dose to aircrews heavily depends, of course, on the number of crewmembers on board, which differs per aircraft type, airline, distance etc. If we assume a direct linear relationship between average numbers of passengers and aircrew members, then the 6%, as mentioned, might be a reasonable percentage.

From the average doses over all the calculated destinations, it would seem that an average of 500 block hours is in better agreement with the working hours of the crew members in the Netherlands than the 1000 used in the exemplifying calculations on the individual dose in section 3.2.1. This is probably due to a large amount of part-time employment.

3.3.2. Passengers

Although individual flight doses have not changed that much in recent years, apart from the modulating effect of the solar cycle, the number of people taking one or more flights per year increased almost exponentially. For instance, the number of passengers in the period considered (1988-1997) doubled. The so-called total number of passenger kilometres performed (passengers x kilometres flown by them) amounted to 96 billion for 1997, which is about 3.7% of the total number of passenger kilometres flown in the world for that year [14]. Based on this percentage, the total collective dose worldwide due to air travel by passengers in 1997 (solar minimum) can be estimated at some 15,000 manSv and for 2002 (solar maximum) at some 16,000 manSv in spite of the lower dose rates.

In recent years frequent flyers (more than 10 flights a year) determine 23% of the collective dose. As mentioned previously, a number of these passengers will appear more than once in the statistics. Especially the Dutch frequent flyers, because they start and end most of their journeys at Schiphol airport, were members of a smaller group of some 83,000 in 1997 with a collective dose of about 45 manSv. Within this group only some 4000 will have exceeded the 1 mSv individual dose, with a group dose of between 5 and 10 manSv.

3.4. Future dose trends

As may be apparent from the above, there are two major factors influencing the collective dose of aircrews and passengers alike: the sun with its 11-year cycle and the number of passengers.

3.4.1. Solar cycle

As mentioned earlier, the dose rate due to cosmic radiation at sea level is only marginal compared with that at flight levels. The same holds for the dose rate variation as a consequence of the solar cycle at sea level. At 39,000 feet the effective dose rate may vary by several thousands of nSv·h^{-1}, while this is only up to about four nSv·h^{-1} at sea level between months of maximum and minimum solar activity.

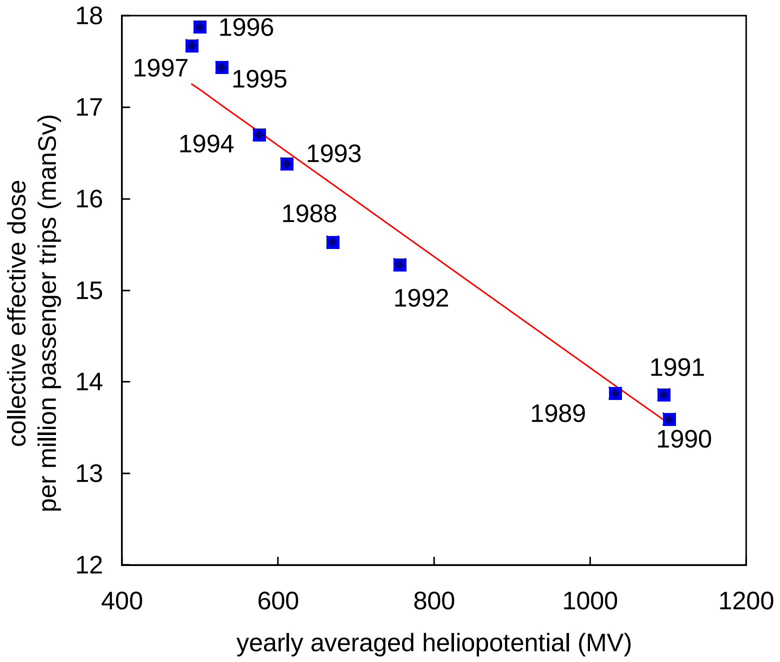

FIG. 6. Collective effective dose per million passenger trips (one way) for the period investigated and a linear fit to these data.

A better view of these variations at flight levels is given in FIG. 6. The collective dose per million passenger trips is apparently correlated with the heliocentric potential. If the distribution of passenger flights around the world going from or to Amsterdam does not change (or, in other words, if the relative growth in passenger numbers is equal over the years for all destinations), this linear fit is then a useful conversion coefficient for use in calculating expected collective doses from the past and for the near future. However, this only applies if the total number of passengers arriving and departing from Amsterdam are known. This linear fit may be different for other airports depending on their geographic locations and the network of connections.

Although not constant over all destinations separately, relative distribution of trips over the last years to all major regions of the world has not deviated much from that in 1991.

3.4.2. The growth in passenger numbers

The growth in passenger numbers was high in the years leading up to 2001. Growth rates at Schiphol Airport of 7-11% were usual in the nineties. Even the relapse in global air traffic after the events of September 2001 (attack in the USA of 11 September) only resulted in a zero growth of passenger numbers in 2001. The consequences of even more recent crises, like the Iraq war and the outbreak of SARS, can not yet be assessed fully.

Besides the temporary relapses due to relatively large crises in the world it is still not extraordinary to expect a return to at least a moderate growth in passenger transport of some 4%. In 1998 the project organisers expected this to be a 'low' scenario for the future Dutch Aviation Infrastructure (TNLI in Dutch) [15]. The 4% is also used in scenario descriptions of the Netherlands Bureau for Economic Policy Analysis (CPB) [9, 16], even after September 2001. In 2000 the International Civil Aviation Organisation (ICAO) even expected a somewhat higher growth rate for Europe [17].

Even for an annual growth rate of 4%, the collective dose will double again in the period 1997-2015.

4. Conclusions and discussion

Because of the growth in aviation worldwide the number of people receiving elevated doses of cosmic radiation have increased considerably. Since the implementation of the new legislation, doses received by aircrews due to enhanced exposures to cosmic radiation have to be collected and retained, similar to other occupationally exposed radiological workers. Some interesting conclusions can be drawn from the detailed research on passenger transport through Schiphol over a period of 10 years, as presented below.

- The total collective dose of all passengers that made use of Amsterdam airport in 1988 amounted to 230 manSv and in 1997 to about 550 manSv. Based on the number of passenger kilometres, this dose is estimated to be 15,000 manSv worldwide for 1997. Based on an expected moderate annual growth rate of 4%, this dose will double again up to 2015.
- Flight doses (single trip) are mostly in the range of 1-60 μSv and are, on average 18 μSv per one-way trip. The high-end dose holds for intercontinental flights to or from North America and East Asia, especially flights that follow a northerly course.
- Most of the Dutch passengers are still once-a-year flyers, but a growing number of especially business people are becoming frequent flyers. An estimated number of 83,000 of them fly on more than 10 trips a year. Some 4000 of them are expected to exceed an annual dose of 1 mSv.
- Members of an aircrew, the only ones affected by the new regulations, are expected to receive annual doses in the range 1.5 – 5.7 mSv for 1000 block hours.
- Although annual doses to passengers normally contribute only a few per cent to the average effective dose from exposure to all sources of radiation, this may be somewhat different for aircrews and frequent flyers, whose annual 'non-flying' exposure may be doubled or tripled.

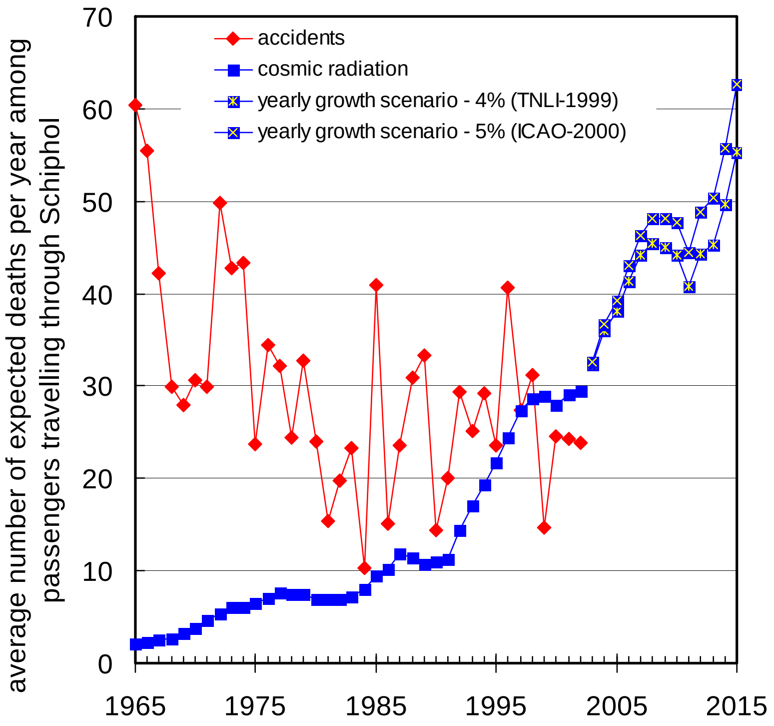

FIG. 7. Average number of expected fatalities per year among passengers travelling through Amsterdam Schiphol Airport. Data on accidents based on Aviation Safety Network [18] and proportion of departures and arrivals at Schiphol compared to the rest of the world. Data on cosmic radiation are taken from the present report. Scenarios from TNLI and ICAO were reported in 1999 and 2000 [15, 17].

If the collective effective dose is multiplied by 0.05, yielding the fatality risk per sievert [4], the number of fatalities that will eventually result from this dose can be calculated. The number of fatalities due to accidents with aircraft can be assessed from the Aviation Safety Network [18]. Based on the number of flights passing through Schiphol Airport, the proportion of fatalities occurring on average in the group of passengers flying through Schiphol can then be estimated. As illustrated in FIG. 7, at the end of the twentieth century both numbers were in balance. The number of fatalities has

either stayed constant or decreased during the past decades, a sign that safety is still improving, considering that the total number of flights and number of passengers per flight have increased.
We can now pose the question: Is flying safe or is it dangerous for the wrong reasons (danger of cosmic radiation replacing danger of accidents)? Or is it all a matter of risk perception?

Although future trends in aviation are still partly hanging in the clouds, we can expect a moderate growth of some 4%. Furthermore, new aircraft types like the 737 Next Generation series have higher cruising altitudes than the present aircraft. Due to crowded skies at altitudes between 10 and 12 kilometres, airlines will try to get round the congestion by trying to fly higher (less influence of the weather, more economical). Furthermore, (small) business planes, often flying at altitudes above the commercial air routes, are becoming more and more common.

References

[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 dangers arising from ionizing radiation, Official Journal L 159 , 29/06/1996 p.0001 – 0114, EU, Luxembourg (1996).

[2] Waters, M., Bloom, T.F., Grajewski, B., *The NIOSH/FAA Working Women's Health Study: evaluation of the cosmic-radiation exposures of flight attendants*, Health Phys. 79(5): 553-559 (2000).

[3] Friedberg, W., Copeland, K., Duke, F.E., O'Brien III, K., Darden, E.B. Jr., *Radiation exposure during air travel: guidance provided by the Federal Aviation Administration for air carrier crews*, Health Phys. 79(5): 591-595 (2000).

[4] International Commission on Radiological Protection, *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Oxford: Pergamon (1990).

[5] UNSCEAR, *United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assemblee*, New York (2000).

[6] Oksanen, P.J., *Estimated individual annual cosmic radiation doses for flight crews,* Aviat. Space Environ. Med. 69(7): 621-625 (1998).

[7] Blaauboer, R.O., *Cosmic radiation during air travel: trends in exposure of aircrews and airline passengers*. RIVM Report 861020004, Bilthoven, the Netherlands (2003), available through the internet at: http://www.rivm.nl/bibliotheek/rapporten/861020004.html

[8] CBS, *Statistiek van de luchtvaart*, jaargangen 1988 tot en met 1997, Centraal Bureau voor de Statistiek, Voorburg/Heerlen (1989-1998).

[9] CPB, *Economie en fysieke omgeving. Beleidsopgaven en oplossingsrichtingen 1995-2020*. Centraal Planbureau, Den Haag (1997).

[10] ICAO, *Outlook for air transport to the year 2010*, International Civil Aviation Organization, ICAO Circular 281 (2001).

[11] Dose model CARI (Civil Aeromedical Institute, Federal Aviation Administration, USA), most recent version available at http://www.cami.jccbi.gov/AAM-600/Radiobilolgy/600radio.html

[12] European Commission, *Recommendations for the implementation of Title VII of the European Basic Safety Standards Directive (BSS) concerning significant increase in exposure due to natural radiation sources*, Radiation Protection 88, Directorate General Environment, Nuclear Safety and Civil Protection (1997).

[13] Van Dijk, J., *Aircrew dose assessment and registration in the Netherlands*, Presentation at the North European IRPA meeting in Utrecht, the Netherlands, 2-5 June 2003.

[14] International Civil Aviation Organization (ICAO), *Annual report of the council 1997, Documentation for session of the assembly in 1998*, Document 9700 (1998).

[15] *TNLI-luchthavenstudies t.b.v. Maasvlakte, Flevoland, Noorzee-eiland*, NACO in opdracht van Ministerie van Verkeer en Waterstaat, Den Haag (1998).

[16] Koning, M., Verkade, E., Hakfoort, J., *Gevolgen van uitbreiding van Schiphol, Een kengetallen kosten-batenanalyse*, Centraal Planbureau, ISBN 90-5833-099-0, Den Haag (2002).

[17] ICAO Update 22 June 2000, also published in ICAO Journal 55(5) (2000).

[18] The Aviation Safety Network, website: http://aviation-safety.net/index.shtml