Protection of Commercial Air Crew and Passengers from Solar Flares and Cosmic Radiation

Scientific, Technical, and Policy Issues

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Why Jet Aircraft Radiation Exposure Is a Concern

- Air crew make up about 3 % of the radiation workers in the world, but receive about 24% of the total collective dose for all exposed workers. The average estimated annual dose for flight personnel is about 2.5 times higher than the combined average for all radiation workers world-wide.

- Certain frequent long-distance airline passengers, such as professional couriers, are estimated to receive annual doses comparable to flight personnel.

- Aircrew are exposed to more biologically damaging forms of radiation, such as neutrons, than the preponderance of other nuclear workers.

- Different exposure estimates agree that the limits to the embryo/fetus are exceeded for pregnant flight personnel working full time on most long-distant jet routes.

- Over the past decade, epidemiological studies of flight personnel show significant increased risks of cancers.

Solar Particle Events (Flares)

- *Cyclic solar flares can increase radiation exposure levels during flight by a factor of 100. S*upersonic Concordes have active radiation instruments that enable pilots to take emergency measures and reduce altitude during flares. The largest flare was measured on the ground in 1956 with a 3,900% increase in neutron rates. In 1989 a flare raised ground-level neutron rates by about 360%.

- The sun has a varying magnetic field with a basic dipole component that reverses direction approximately every 11 years. At "solar maximum" there are many sunspots which yield large plasma" bursts" of protons and electrons. This is called "the solar wind." *Between 1956 and 1993, roughly 1,305 sunspots were observed on Earth.*

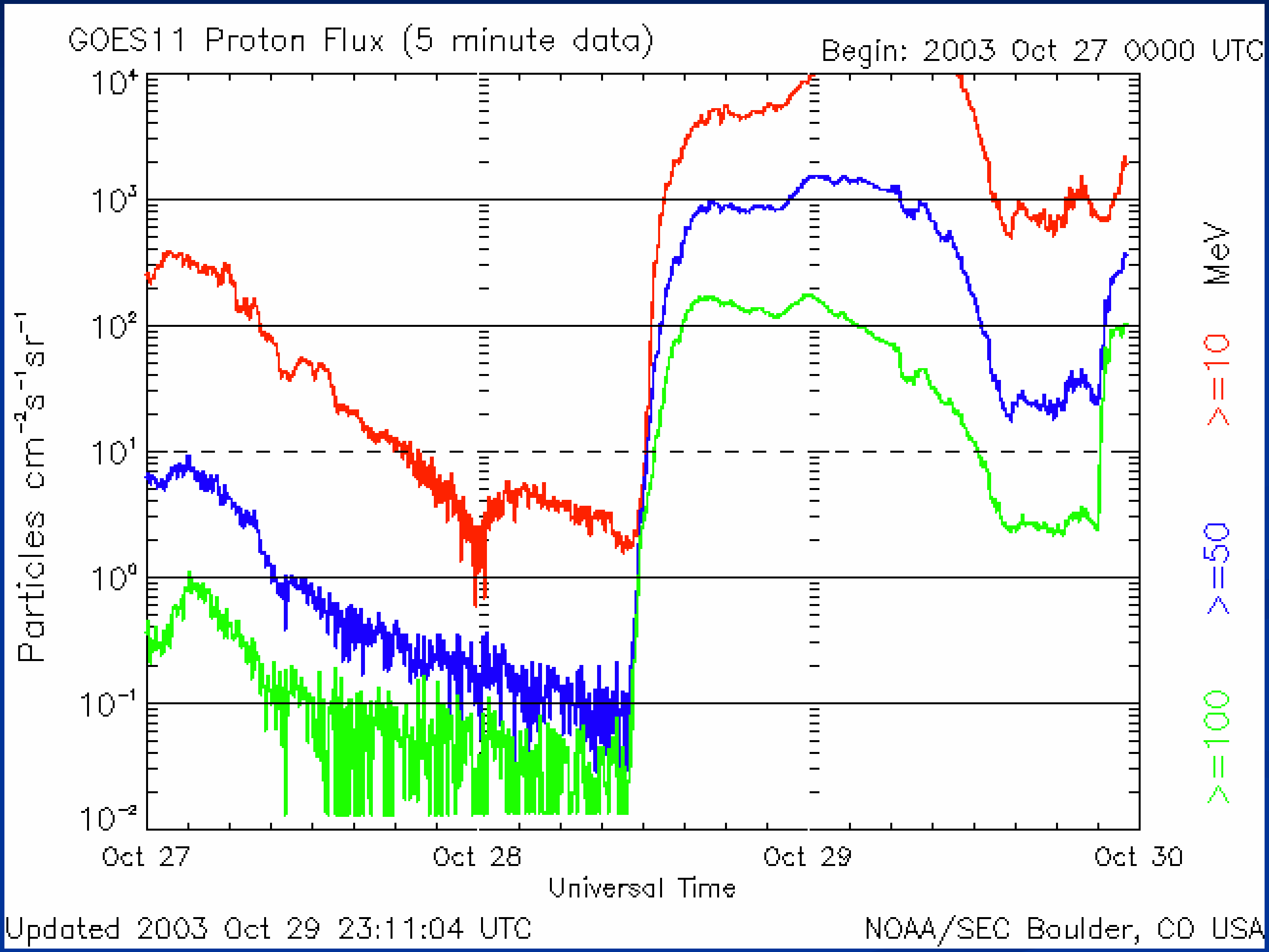
- When the solar magnetic field is weaker it is called the " solar minimum" and is the time of maximum radiation events hitting the Earth. *Between 1956 and 1991 about 49 estimated flares were strong enough to be measured on the ground.*

- *Solar Flares* are largely unpredictable and accelerated particle "shock events"– where prompt, enormous bursts of radiation occur, are completely unpredictable.

A Recent Solar Particle Event

GOES11 Proton Flux (5minute data)

October 27, 2003 – to October 30, 2003



NOAA/SEC Boulder, CO, USA

Note the sharp and sudden rise in the density of high-energy particles over a period of minutes.

Estimated Exposures to Radiation Workers World-Wide

Category	Number	Collective dose and% of total	Average dose equivalent/yr and % of total
Nuclear Fuel Cycle	450,000	1,400 Man Sv=42%	1.75 mSv=30%
Medical Uses	2,320,000	760 Man Sv=23%	0.33 mSv=6%
Industrial Uses	700,000	360 Man Sv=9%	0.51 mSv=9%
Defense Activities (US/UK)	139,000	33 Man Sv=1%	0.25 mSv=4%
Air Crew	250,000	800 Man Sv=24%	3.0 mSv=51%
Total	3,859,000	3,353 Man Sv	0.168 mSv (average of total)

Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report, Vol I. Annex E.

Cosmic Radiation and Frequent Flyer Passengers

- ICRP Publication 60 (1991) recommends that attention should also be paid to groups of frequent flyer passengers who are estimated to receive annual doses above 1mSv.

- Based on an analysis from London Airport, professional couriers took 200 journeys a year – implying 1,200 hours and an annual effective dose of 6 to 10 mSv.*

- In Germany, about 20,000 passengers are estimated to receive annual doses above the 1 mSv limit set for the general public.*

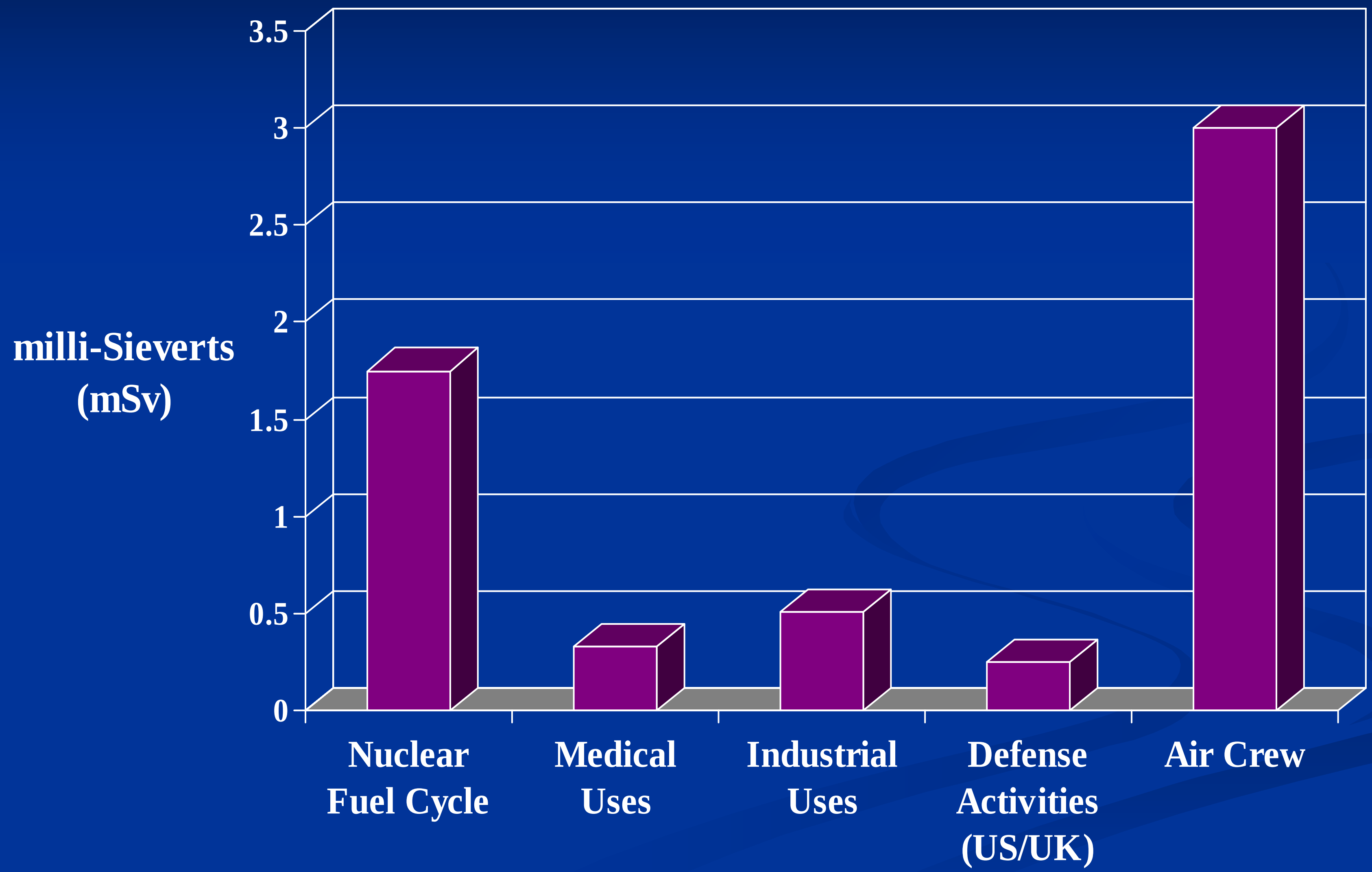
- The European approach is to advise employers of frequent long-distance travelers to take necessary steps to determine radiation doses, using the same methods adopted for air crew.+

- The United States informs frequent long distance travelers and their employers about doses through a largely unadvertised internet web page of the FAA.

* UNSCEAR 2000, Annex E. Section 240, p.538.

+ McAulay, I, Health Phys 79(5), 2000.

Annual Exposures to Radiation Workers World-Wide



Radiation Risks to Pregnant Flight Crew

- Childhood cancer is strongly linked to radiation exposure in utero. It is the single largest cause of death by disease among children in the US.

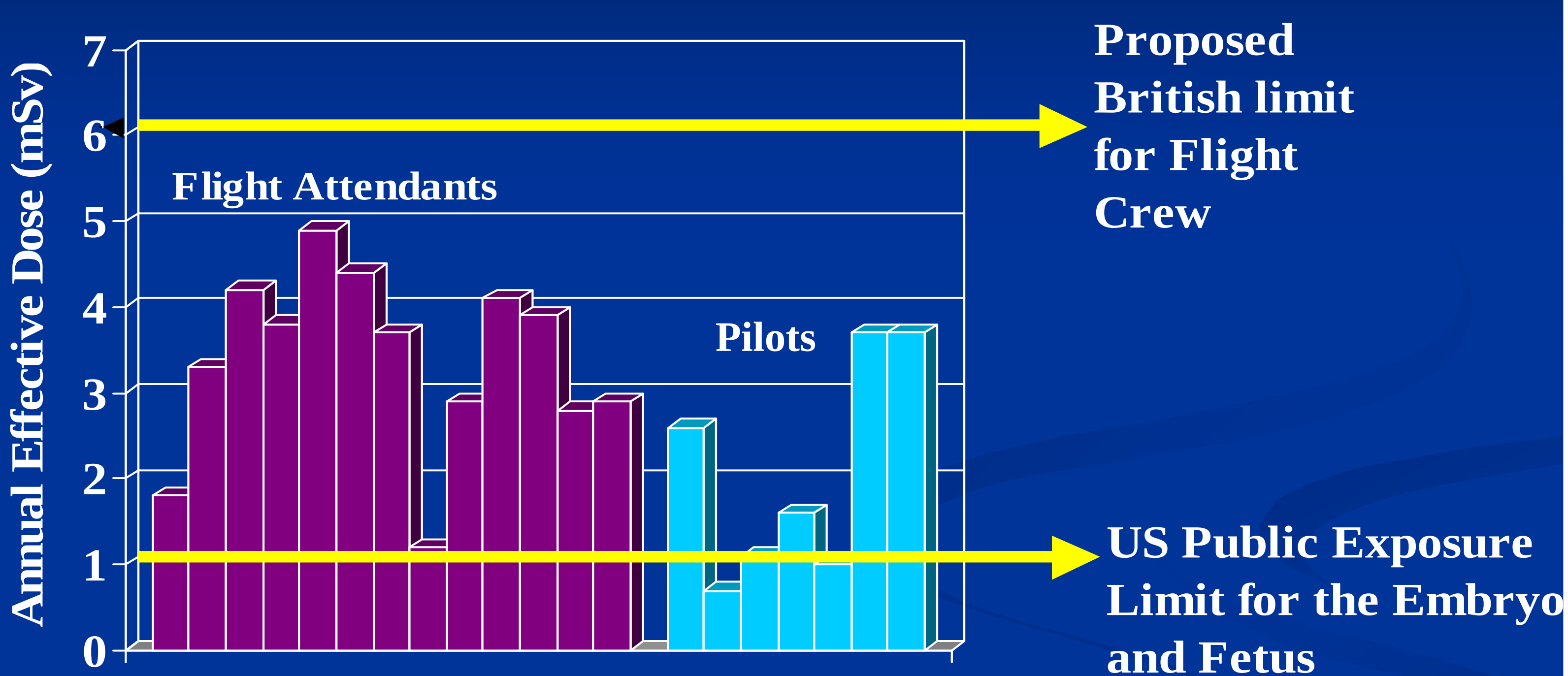
- The first human evidence linking childhood cancer to fetal radiation exposure was reported in 1955 (Stewart and Hewlit). According to Stewart and Kneale (1970), a single pelvimetric x-ray doubles the risk of childhood cancer.

- In the late 1970's the US Food and Drug Administration advised physicians and patients against the use of routine fetal x-rays. US and other countries have adopted limits to protect pregnant nuclear workers.

- Recent studies on developmental injury in mice embryos indicate a larger Quality Factor or RBE is required for protection in prenatal exposures (Jiang et. Al, 1994).

- According the Otake and Schull (1998) the most radiosensitive stage of pregnancy among Japanese atomic bomb survivors is 8 to 25 weeks.

Flight Crew Dose Estimates



Individual Dose Measurements of Canadian Flight Crew (1993)
Tume et al, Health Phys. 79(5) Fig. 9.

Programs to Protect Radiation Workers in the United States

USEPA –Federal agencies implement radiation protection standards based on EPA guidance authority, under the Atomic Energy Act.

Nuclear Fuel Cycle – OSHA and the NRC regulations limit exposures to uranium miners under binding and enforceable federal standards. (10 CFR 20)

Department of Energy – DOE regulations limit exposures to nuclear weapons and nuclear research workers under binding and enforceable federal standards. (10 CFR 835)

Industrial Uses – OSHA regulations limit exposures under binding and enforceable federal standards.(29 CFR 1910 and 10 CFR 20)

Medical Uses – The Food and Drug Administration regulates equipment design and states inspect and enforce regulations. (21 CFR 1020)

Flight Crew – The Federal Aviation Administration issued a non-binding Advisory Circular regarding training in 1994, and made dose estimation tools (CARI Code) available on the internet.

European Union Adopts Radiation Protection of Air Crew

- **1991 –** The International Commission on Radiological Protection (ICRP) recommends that air crew members are to be considered as radiation workers, and that attention should also be paid to groups who fly more than other passengers. The ICRP recommends that worker exposures are limited to 20mSv/yr and the public dose is limited to 1mSv. Onboard monitoring and medical surveillance should be required where doses exceed 6mSv/yr.

- **1996 --** The Commission of the European Communities issued a Directive, which requires Member States to establish a protection programs for exposure to cosmic radiation of air crew who are liable to receive more than 1mSv/yr. Article 42 specifically requires Member States :

  ***** to assess the exposure of air crew concerned;

  ***** to take into account the assessed exposure when organizing working schedules to reduce doses of highly exposed air crew;

  ***** to inform the workers concerned of the health risks their work involves; and

  ***** to require the employer to limit pregnant air crew exposure to 1mSv/yr.

The European Approach to Assessing Exposures

- **Direct measurements** use an active instrument to give an immediate figure for the dose rate. This is probably the best way to obtain an accurate dose rate aboard an aircraft at anytime. However, active instruments are not easy to make and require fairly complex equipment and experienced operators.

- **Passive detecting systems** record the dose received by using different types of material which are affected by radiation in a detectable way. These systems are excellent for giving the total dose received over a fairly extended period but require complex calibration techniques and careful storage when not in use

- **Computer codes** enable the dose to be calculated for any given path and altitude of an aircraft flying any route. The European view is that an assessments using computer codes are sufficient for radiation protection purposes with the proviso that the codes undergo periodic review and update.

The European Approach to Controlling Exposures

- Employers are responsible for informing workers about the doses they receive and for providing information about the possible effects on health of such doses.
- Female crew are made aware of the need to control doses during pregnancy and the employer should be informed when pregnancy is recognized so that appropriate control measures can be introduced.
- Crews of aircraft which operate at altitudes of 8 km and less <u>do not</u> require controls to assess or limit their exposures.
- Doses to crew who may receive more than 1 mSv/yr should be assessed.
- Individuals who receive more than 6 mSv/yr trigger more detailed medical surveillance and more stringent requirements. These additional requirements include warning signs and individual dose measurements.

The Importance of Altitude and Latitude for Radiation Protection

- Earth’s atmosphere is a massive shield protecting life on earth from cosmic radiation. At sea level, this atmospheric shield is roughly equivalent to a wall of water 10m thick because of its mass thickness. With the rise in altitude, atmospheric shielding decreases and radiation doses increase.

- Dose-rates from cosmic radiations at 30,000 feet increase by 90 times the rate at sea level then by about a factor of two from 40,000 to 65,000 feet.

- The Earth’s magnetic field deflects radiation and provides latitude-dependant protection. The joint effects of shielding by the atmosphere and the magnetic fields of Earth mean that, at a height of 10 km, typical of conventional jet aircraft , the dose rate is roughly twice as high at the poles as at the equator

The Atmospheric Radiation Environment

- The radiation environment in Earth's atmosphere is very complex and encompasses a range of types of ionizing particles at energies and intensities not experienced in normal occupational exposures at ground level.

- The earth is continually bathed in high-energy ionizing radiation called "galactic cosmic rays." They come from outside the solar system and also from sporadic bursts from the sun called solar particle events (SPE).

- Primary cosmic ray particles undergo a variety of reactions when they hit the upper atmosphere. They fall into three types: nucleons (protons and neutrons), electromagnetic (electrons and photons) and muons.

- At aircraft altitudes of about 18 km and below, high energy subatomic particles collide with atoms of elements in the atmosphere, producing a great variety of secondary high energy particles, such as neutrons.

High-LET Radiations

- High-LET (linear energy transfer) radiations are either charged or neutral subatomic particles, which transfer high energies as they travel through tissue. Low-LET radiation such as x-rays are around 70 thousand election volts (70 KeV), while cosmic neutrons range from several hundred KeV to 100 million election volts (100MeV) and beyond.

- At aircraft altitudes, the primary cosmic rays have given way to a great variety of secondary (or later) particles, some of which will be very high energies, most notably electrons, protons, high-energy neutrons, photons, and sometimes high-Z particles. This is not a situation that arises elsewhere in radiation protection, except perhaps around high-energy particle accelerators

- At all altitudes from 10,000 to more than 80,000 feet (3 – 25km) <u>neutrons are the dominant component of radiation exposure.</u> The are less dominant at lower altitudes, but still the most important component contributing about 40-80% of the total dose equivalent rate. By comparison about 3% of radiation doses to nuclear workers is from neutrons and other high-LET radiations.

Biological Risks of Neutrons and Other High-LET Radiations

- According to the National Academy of Sciences (NAS), neutrons are 20 times more harmful to humans than x-rays or gamma rays. This is because neutrons cause greater damage to cell constituents such as the DNA.*

- Recent human cytogenic data from lymphocytes exposed to similar radiations at commercial jet altitudes, suggest that cosmic neutrons may be 90 to 113 times more harmful, than currently assumed. **

- Protons, charged particles that are a form high-LET Radiation encountered at commercial jet altitudes, are considered to be 2 to 5 times more harmful than x-rays.

* The NAS found that: "The carcinogenic and mutagenic effectiveness of neutrons and other high LET radiations remain constant or may even increase with decreasing dose… high-LET radiations are more cytotoxic and oncogenic than low-LET radiation such as x-rays and gamma rays. Furthermore the RBE for oncogenic transformation and cytotoxicity increases with increasing LET of the radiation ." (Source: National Academy of Sciences, Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR V), 1990).

- **Anna Hiemers, Cytogenic analysis in human lymphocytes after exposure to simulated cosmic radiation which reflects the inflight radiation environment, Int. J. Radiat. Biol 1999, Vol. No. 6, 691-608.

Annual Radiation Flight Crew Doses Based on Neutron Quality Factors (RBE)

RBE = 20*	**RBE= 90 to 113****
3 mSv/yr (average)	10.1 mSv/yr –11.5 mSv/yr (average)
10 mSv/yr (high)	33.8 mSv/yr –47.4 mSv/yr

* ICRP 1991, **Anna Hiemers, Cytogenic analysis in human lymphocytes after exposure to simulated cosmic radiation which reflects the inflight radiation environment, Int. J. Radiat. Biol 1999, Vol. No. 6, 691-608.

Comparison of High-Let Penetrating Exposures between U.S. Nuclear Weapons Workers and Flight Personnel

Category	Collective dose	Average dose equivalent and % of total
US Nuclear Weapons Industry	14.4 Person Sv*	0.78 mSv = 3%
Air Crew	544 Person Sv**	2.04mSv = 97%

* UNSCEAR 2000, Annex E. ** Wilson, Health Physics, 79 (5); 2000 (68% of dose is assumed to be from neutrons)

Technical and Scientific Uncertainties

- Because of the random and heterogeneous nature of cosmic radiation, exposure estimates and measurements have significant uncertainties relative to dose-rates and radiation energies (particularly with respect to neutrons).

- Neither the biological effects of neutrons and other high-LET radiations relative to long term consequences of persistent chromosomal rearrangements, nor the long term effects of enhanced role of particle radiations in inducing genomic instability, are well understood

- Solar Flares and accelerated solar "shock" events cannot be predicted in terms of frequency and severity.

- The aircraft environment includes other potential and multiple risk factors which are not as well understood as radiation, such as electromagnetic fields, changes in body hormones, time zone changes, pesticides, pressure changes, chronic fatigue, and life-styles.

Summary of Epidemiological Studies of Flight Crew

- Over the past decade, some eleven studies indicate that flight personnel are experiencing increased risks contracting various cancers. There are other potential risks factors, in addition to radiation, which add uncertainties as causal factors. Cancer sites of particular interest are:
  - ✓ female breast+
  - ✓ skin
  - ✓ leukemia+
  - ✓ male brain +
  - ✓ male bladder+
  - ✓ male rectum/colon+
  - ✓ bone+
  - ✓ prostate+

- Several studies are still underway which include NIOSH studies of cancer and birth outcomes of flight attendants, a pooled study of European flight crew, and studies by the Airline Pilots Association.

+ Covered under the Energy Employees Compensation Act of 2000 (P.L. 106-398, Title 35)

Recent Epidemiological Studies of aircrew and significant findings

Study	Type	Significant Findings	RR	Number of cases
U.S. Air Force 59,940 aircrew (Grayson and Lyons 1996a)	Cohort, SIR cancer incidence comparing hospitalizations with SEER rates	All cancer	1.19	342
		Melanoma	1.50	49
		Non-melanoma skin	1.45	36
		Bladder cancer.	2.09	19
		Hodgkin's disease	0.51	14
		Leukemia	0.9	13
		Cancer of the bone	1.4	6
		Colon/Rectum cancer	1.3	20
U.S. Air Force brain cancer (Grayson and Lyons 1996b)	Case-control 230 cases and 920 controls, air crew and non-flying officers	Unadjusted risk	1.77	1.2-2.7
		Adjusted for military rank	1.22	0.8-1.9
Canadian Pacific Airline Pilots (Band et al 1990	Cohort, SMR 913 pilots	Rectal cancer	4.4	3
		Brain cancer	4.2	4
		All causes	0.63	71
	Cohort, SIR	brain Cancer	3.5	4
		Prostate cancer	3.9	3
		Non-melanoma skin	1.5	26
		Hodgkin's disease	4.5	3

Recent Epidemiological Studies of aircrew and significant findings

Study	Type	Significant Findings	RR	Number of cases
Air Canada (band et al 1996)	Cohort, SMR	All cancers	0.61	56
	2,740 pilots, 219 deaths	Leukemia	4.72	
		Lung cancer	0.25	8
		Circulatory diseases	0.60	81
		All causes	0.63	219
		Brain cancer	1.4	
		All cancers	0.71	125
		Melanoma	1.5	8
		Colon Cancer	1.2	13
	Cohort SIR	Lung cancer	0.28	11
	Cancer incidence	Bladder cancer	0.36	4
	* 95% CI =0.83-3.5	Rectal cancer	0.42	4
		Prostate cancer	1.87	34
		Non-chronic lympho- Cytic leukemia	1.88	7
British Airways (Irvine and Davies 1992)	PMR	All cancers	1.31	138
	Death notifications	Brain cancer	2.68	9
		Colon cancer	2.30	
		Prostate cancer	2.12	10
		Melanoma	6.68	6
		Myloid leukemia	2.3	4

Recent Epidemiological Studies of aircrew and significant findings

Study	Type	Significant Findings	RR	Number of cases
British Airways	Cohort, SMR	Melanoma	5.6	6
(Irvine and Davies 1999)				
	6,209 pilots and			
	1,153 flight engineers			
Finnair cabin attendants				
(Pukkala et al. 1995)	Cohort, SIR	All cancer	1.2	35
	Cancer incidence	Breast cancer	1.87	20
	1,764 flight attendants	Bone cancer	15.1	2
	(1,577 females)	Brain Cancer	0.5	
		Melanoma	2.1	3
		Leukemia	3.6	
Danish female cabin attendants	Cohort SIR			
(E.Lynge 1996)	915 female attendants	Breast cancer	1.61	
Danish cockpit crew	Cohort SIR	All cancers	1.2	
(M. Gundestrup and H. Storm 1999 a)	Cancer Incidence	Acute myeloid		
(not adjusted for				
				for flying hours)
	3877 cockpit crew	leukemia	5.1	
	flying more than	Skin cancer	3-0	
	5000 hours	(excluding		
	169 total cancers	melanoma)		
		Melanoma	2.5	

Recent Epidemiological Studies of aircrew and significant findings

Study	Type	Significant Findings	RR	Number of cases
Icelandic Air Pilots* (V. et al Rafnsson 2000)	Cohort SIR Cancer incidence 485 pilots	All cancers	0.97	
		All Cancers (international routes)	1.16	
		Melanoma	10.2	
		Melanoma (high exposure estimates, flying) over 5 time zones)	28.57	
California Flight Attendants (USA) (Peggy Reynolds et al 2000)	Cancer Incidence PIR 6,000 flight attendants	Breast cancer	1.35	60
		Melanoma	1.67	12
		Lung cancer	0.37	3

* Based on abstracts.