COSMIC RADIATION AND FLYING

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Flight crew, including full-time flight attendant and pilots spend an average of 700-1000[1] hours at altitudes of 10 000 m or higher in a given year. Given the number of hours spent in the air by cabin crew and pilots and the increasing number of frequent flyers, there has been increased concern on the health effects of cosmic radiation. Many countries now even recognize flight crew as occupationally exposed workers[2]. This research project will investigate the accumulated radiation exposure from a return trip from Toronto to Tokyo. It will discuss what research has been conducted to understand the risks that these workers and frequent flyers face as well as what the perceived and understood risks by both groups are. Data on perceived risks were collected via a questionnaire and actual risks were gathered using published literature.

Cosmic Radiation

Cosmic radiation consists of high energy particles originating from the sun. These high energy particles interact with the earth's upper atmosphere creating a shower of lower energy particles. At higher elevations, exposure to cosmic radiation is greater when compared to those received at sea level. At sea level, the major component of cosmic radiation is muons while at higher altitudes cosmic radiation is dominated by neutrons, electrons and protons[3].

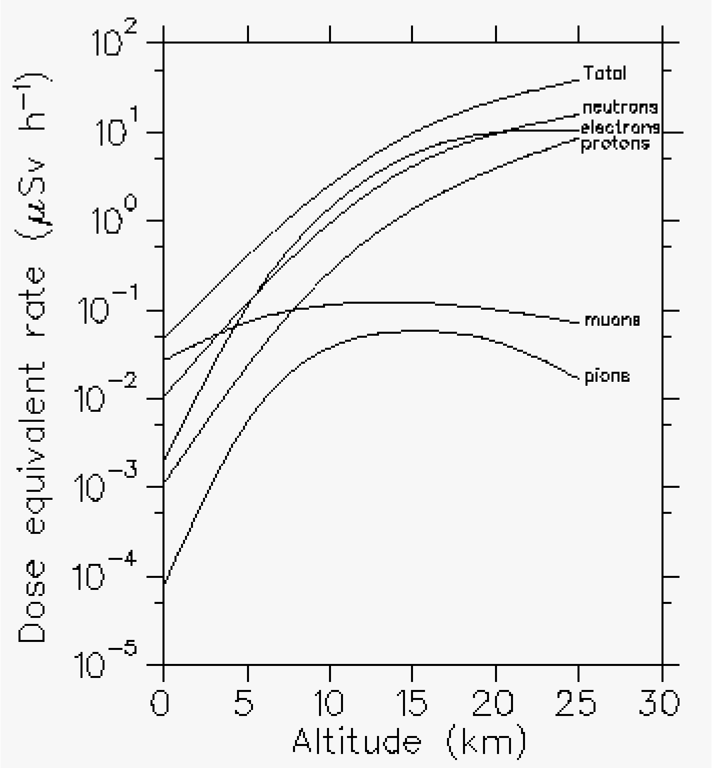

Figure 1: Equivalent Dose Rate for different particle types as a function of height in the atmosphere. Source: http://www.triumf.ca/EHS/rpt/rpt_4/node3.html

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[1] *US Department of Labor http://stats.bls.gov/oco/ocos171.htm*

The amount of cosmic radiation reaching the earth's surface also varies depending on the latitudinal location. Since cosmic radiation is composed of charged particles, it can be deflected by the Earth's magnetic fields. Higher levels of cosmic radiation are therefore experienced at higher latitudes, towards the Earth's magnetic poles[4].

Health Effects

A number of studies have looked at the possible biological consequences of frequent exposure to increased levels of cosmic radiation from flying. From the studies looked at in this paper, the main biological consequences of concern include leukemia and other cancers[5], genomic aberrations[6], damage to fetus' during pregnancy[7] and effects on mortality rate[8].

Studies conducted in North America on cancer incidence show varied findings. A major survey conducted among US Air Force crew[9] noted a significant increase in incidents of cancer of the testis, bladder and all cancer site combined when compared with non-flying officers. However, a study conducted on Air Canada pilots showed that an increased risk of prostate cancer and acute myeloid leukemia exists while levels of rectal, lung, bladder and all other causes of cancers decreased[5].

In Finland, a large study conducted by Pukkala et al[10] found significant excess occurrences of bone (15-fold increase) and breast cancer (1.9-fold increase) among female flight attendants while risks of leukemia and skin melanoma remained unchanged when compared to the national average. From a study conducted based on British Airways flightdeck crew[8], it was found that the flightdeck crew actually lived longer than the general population in the England and Wales population and that there was no incidence of mortality which could be directly linked to cosmic radiation exposure.

Damage to a fetus during a flight is of large concern because of the known increased radiosensitivity of young children, the elderly and fetus to ionizing radiation[11]. Most airlines allow pregnant women to fly up until their third trimester of pregnancy[2] (36 weeks). For pregnant crew members the recommended exposure is limited to 0.5 mSv (NCRP 1993) during the month in which pregnancy is reported to management and 1 mSv during the remainder of the pregnancy (ICRP 1991, 1997)[13].

The major area of concern for the pregnant women and the fetus is the accumulation of genetic damage due to radiation exposure as this could have detrimental affects on the newborn. While no cases of detrimental effects on the fetus of a pregnant mother exposed to high levels of cosmic radiation are reported here, studies have shown that cosmic radiation causes cytogenetic damage. Notably, Romano et al[6] conducted a study based on pilots and aircrew of the Italian national carrier and found increased levels of dicentric and ring chromosomes in the peripheral blood lymphocytes of flight personnel which were of statistical significance. However, Romano points out that while dicentric and ring chromosomes are potentially lethal forms of damage, they are unstable in that they disappear after several cell divisions. Therefore, dicentrics and ring chromosomes are not confirmed as good indicators of the onset of mutational cancer, hereditary disorders nor should they be used for individual risk assessments.

Measurements

There are many ways to measure radiation; ion chambers, Geiger-Mueller counters, thermo luminescence detectors and so on. Radiation exposure can also be measured using an electronic personal dosimeter (EPD) or a thermoluminescent dosimeter (TLD). TLDs accumulate dose from the time that it was first used until it is processed while EPDs captures dose only while it is on and provides dose information in real time.

TLD Measurements

The thermoluminescent dosimeters (TLDs) which were used (Global Dosimetry Solutions, TLD-760) can be used to record the level of radiation exposure from gamma, x-ray, beta and thermal neutron radiations. It is useful in determining doses for deep and shallow tissues as well as for the lens of the eyes[12]. Once the dosimeters have been worn for the prescribed period, they can be sent back to the company where tiny chips held inside of the dosimeter casing are removed and readings of the accumulated radiation exposure can be produced. The results are then sent back to the clients for review. Most commonly, TLDs are employed to monitor the amount of radiation exposure accumulated by occupationally exposed workers in nuclear medicine facilities, nuclear power plants, research laboratories, hospitals, universities and in a variety of industries that use radiation.

TLDs collect dose information via small chips made of thermoluminescent materials. Materials that have thermoluminescent properties give off visible light when they have been exposed to radiation and are subsequently heated to sufficiently high temperatures. Commonly used thermoluminescent materials are inorganic crystals such as calcium sulphate ($CaSO_4$) or calcium fluoride (CaF) doped with impurities such as manganese (Mn). We call impurities such as Mn, activators. When radiation interacts with the crystal, it deposits all or some of its energy into the atoms of the crystal causing it to become ionized. This process of ionization produces free electrons and areas which lack the liberated electrons, called holes. There is also another kind of ‘hole’ known as electron traps, which are inherent in the crystal, mainly from the introduction of impurities, like Mn. When electrons are liberated by radiation, they will travel until they reach one of these electron hole traps. The trapped electrons within the crystal will stay in these hole traps until the radiation dose is ready to be read from the crystal.

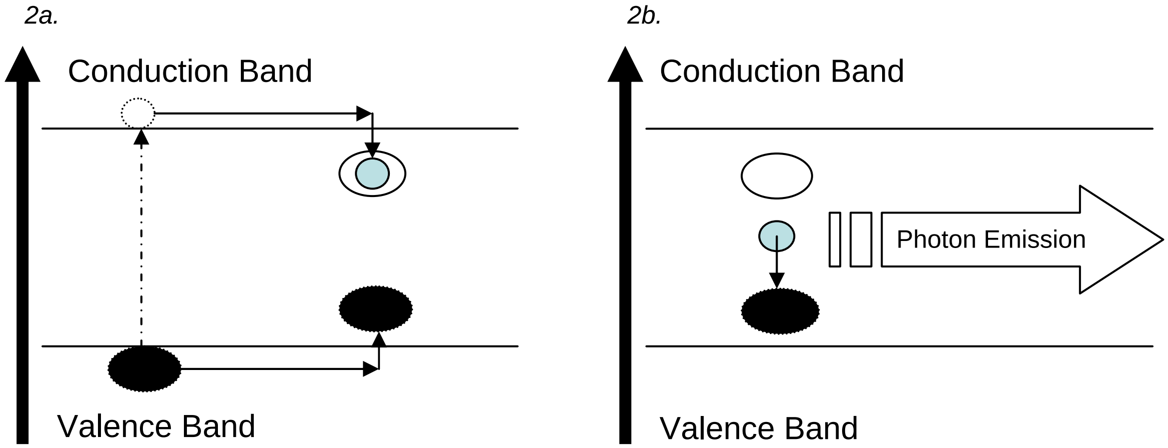


Figure 2a: An electron (small filled circle) exposed to ionizing radiation absorbs energy and is liberated to the conduction band and trapped in an electron trap (empty oval). Figure 2b: Upon heating, the electron releases energy as light and recombines with a hole trap (filled oval). Source: Adapted from Medical Physics 4R06 course notes.

The dose accumulated by the crystal will be proportional to the number of electrons which have been liberated by the radiation of interest and trapped in the hole traps. When these crystals are exposed to high enough temperatures the trapped electrons will be released from their traps, giving off energy in the form of light. By measuring the amount of light released, the number of electrons can be determined and used to calculate accumulated dose. The temperature required to release trapped electrons will vary depending on the material of the crystal. Figure 3 gives several examples of TLD materials and their annealing temperatures – the temperature required to release trapped electrons.

TLD Material	**Treatment Temperature**	
	In Oven	**In Reader**
LiF:Mg,Ti (TLD-100,600,700)	10 min at 100ºC	20 sec at 160º
LiF:Mg,Cu,P (GR-200A)	10 min at 130ºC	20-30 sec at 160º
CaF_2:Dy (TLD-200)	10 min at 110ºC or 10 min at 115ºC	16 sec at 160º
CaF_2:Tm (TLD-300)	30 min at 90ºC or 10 min at 115ºC	16 sec at 160º
$CaSO_4$:Dy (TLD-900)	20-30 min at 100ºC or 5 min at 140ºC	16-32 sec at 120º
$CaSO_4$:Tm	20-30 min at 100ºC	16-32 sec at 120º

Figure 3. Various TLD crystal materials and required treatment temperatures. Source: http://www.worldscibooks.com/phy_etextbook/5167/5167_chap1.pdf

By plotting the intensity of the light released versus the temperature, a peaked curve results. This curve is known as a glow curve. The area under the curve is proportional to the number of electrons trapped. Therefore the area under the curve is what will give us information about accumulated dose.

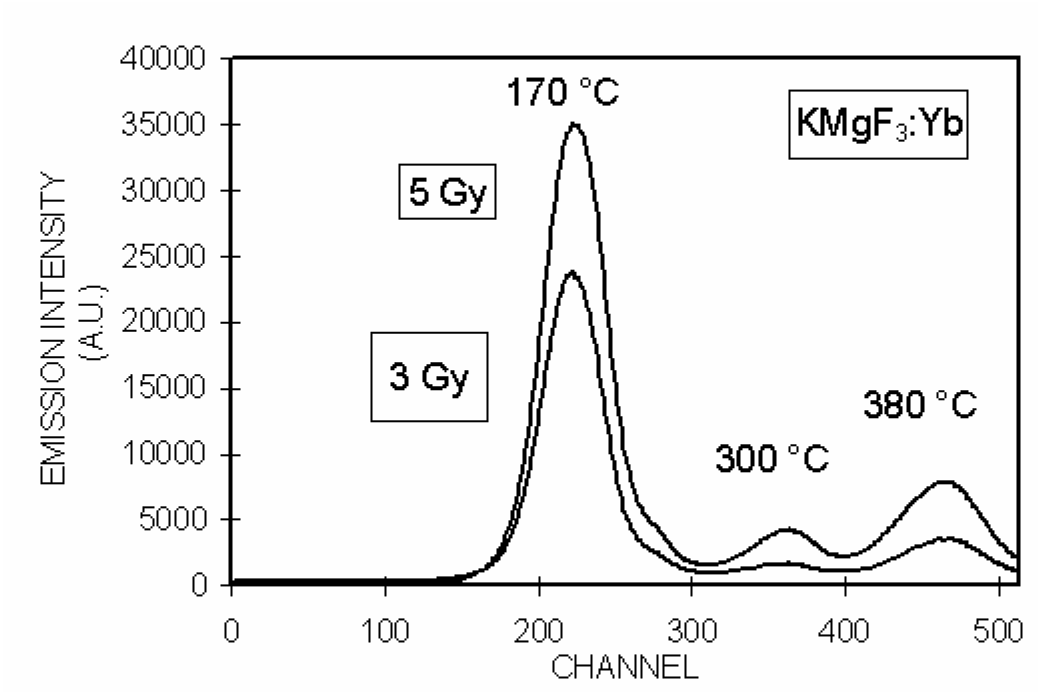


Figure 4. Example of a glow curve. Glow curves of KMgF3:Yb at 3 and 5 Gy. Source: http://users.unimi.it/~frixy/tld/tld_main.htm

One of the great advantages of TLD chips is that they are reusable. Once a TLD chip has been read it can be reset by prolonged exposure to high temperatures within a heating oven.

Electronic Personal Dosimeter (EPD)

The type of detection device used in the electronic personal dosimeters (EPDs) is a semi-conductor. Semi-conductors are used instead of other types of detectors for many reasons; they have much higher energy resolution, they are more efficient, they are more sensitive, they are very compact (so you can wear them on your body) and they have fast readout times (so you can get your dose in real time.)[13] There are several materials that make good semi-conductors. EPDs use silicon as a material because it is a good semi-conductor, but more importantly, it responds to and absorbs radiation very similarly to tissue.

The way a semi-conductor acts as a detector can be somewhat complex, but fundamentally is very simple. When gamma, x-ray or sometimes beta radiation passes through the semiconductor, it transfers energy to an electron in its pathway and excites it to a conduction band, thus creating an electron-hole pair. A whole bunch of electron-hole pairs are created along the pathway of the incident radiation. Excited electrons can also create electron-hole pairs themselves, these are called secondary electrons. Meanwhile, an external electric field is applied across the semiconductor causing the electron-hole pair to move and create a current. The electrons are then collected at an electrode connected to the semiconductor and a pulse is measured through a resistor. The pulse has an energy peak that is proportional to the energy of the gamma ray. A dose is determined by integrating the pulses with respect to a reference voltage. A dose rate can also be measured with an EPD. Dose rates are measured by reading step by step shifts in the reference voltage.[14] This diode system is then connected to a little computer.

The computer is quite strong and can calculate many useful dosimetry quantities. One important quantity is equivalent dose which takes into account two main factors: the type of the radiation (which is assumed to be gamma or x-ray radiation for an EPD), and the energy of the pulse. Two equivalent dose values are calculated: a deep tissue dose and a shallow tissue dose. The units the doses are reported in are “rem” which is an old unit that stands for “roentgen equivalent man.” The computer of the EPD has memory so it can store information to later on produce a histrogram if necessary. The computer also has alarm settings for both the dose and dose rate. These settings can be adjusted to suit the user’s needs. These factors are what truly set apart EPDs from TLDs.

The Study and Experiment

The purpose of this study was threefold. The first goal was to get an indication of the public’s perception of cosmic radiation and flying. The second goal was to get an actual measurement of dose from cosmic radiation while flying and the third was to assess whether airline crew members should be classified as occupationally exposed and wear radiation dosimeters.

Public Perception Survey

Two simple questionnaires were created and sent out to two groups: 1) airline crew members and 2) non-crew members (also referred to as passengers.) The surveys were brief and asked a variety of questions. For a complete look at the surveys, please see appendix A. There were 3 crew members and 20 passengers surveyed. One of the questions asked was, “How much radiation do you think you are exposed to in a given year of flying (assume you fly somewhere between 600-800 hours during the year) when compared to the average amount of radiation exposure accumulated through man-made (medical) and natural radiation sources? LESS, SAME or MORE?” The responses to this question are tabulated in figure 5 and are quite interesting.

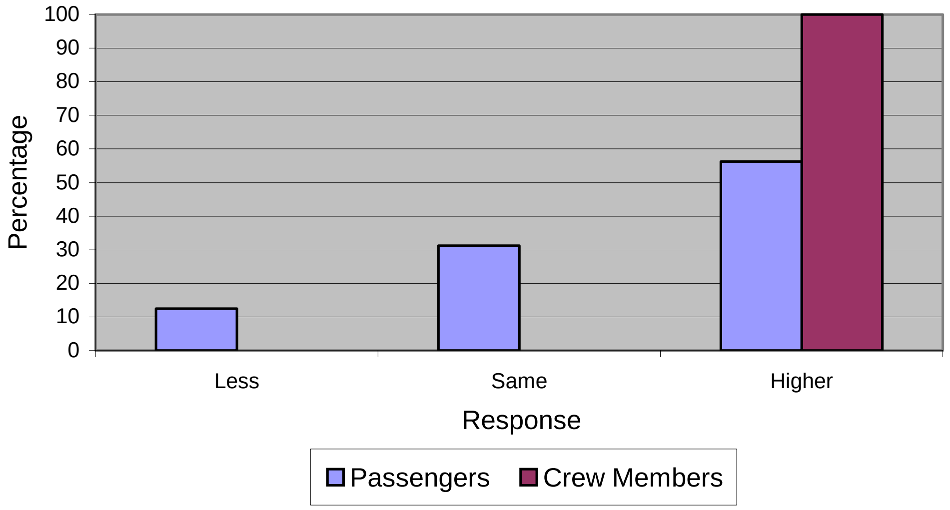
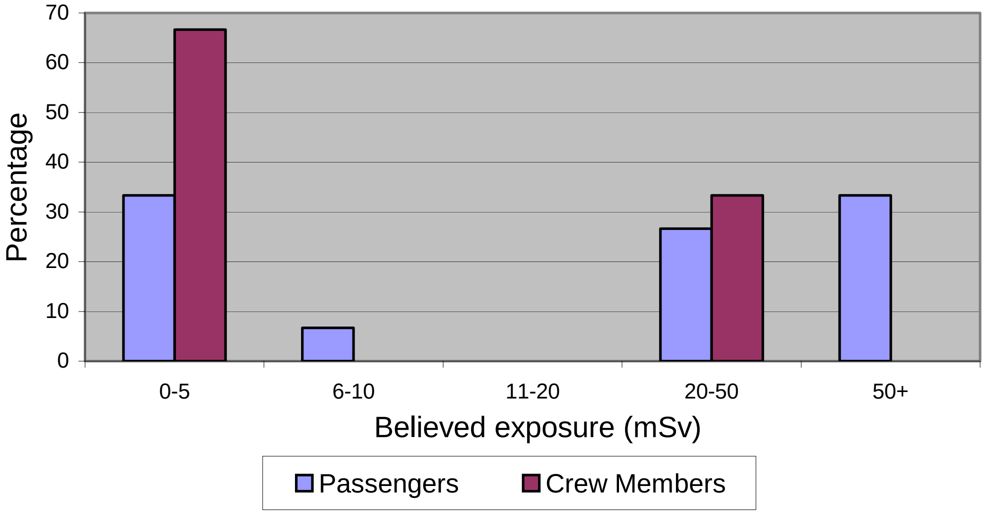


Figure 5: The public's preception of radiation exposure during an international flight when compared to staying on the ground

From figure 5, it can be seen that the public has a varied sense of what the radiation exposure is while flying. For passengers surveyed, the response is across the board: 56% think that radiation exposure while flying is higher than background, 31% think it's the same and a whopping 13% think that radiation exposure while flying is less then the exposure on the ground. For airline crew member, 100% of those surveyed felt that radiation exposure is higher while flying then while on the ground. All of this is fine and dandy, but these responses don't exactly give us an indication on HOW MUCH less or more the public thinks radiation is while flying when compared to being on the ground. So the following question was asked: "Given that an average x-ray examination accumulates 5 units of radiation, how much radiation do you estimate on a 12 hour flight from London to Tokyo at a cruising altitude of 10 000m?" The responses are displayed in figure 6.

From figure 6, it is rather clear that the public really does have a wide-ranged view on how much dose one receives while flying, which comes as no surprise. Some people felt that you get a dose that's less then a single a chest x-ray whiles others thought you get more than 10 times the dose of a chest x-ray. The interesting results were from the crew members. They responded very similarly to the general public. Most of the crew members felt that the dose was less than or equal to the dose from an x-ray but there was a significant group, about 1/3 of the population, who felt that a cross continental flight will give you 10 times the dose of a chest x-ray.

Figure 6: The public's estimate of the dose received while flying on a 12 hour flight from London to Tokyo at 10 000m



A valid explanation for these polar responses could be and most likely is, lack of education. When asked if they have ever been informed by their employer of the risks of being exposed to elevated levels of radiation from flying, 100% of the crew members replied “NO”.

As a final question, it was asked if they believe it to be worth while to have airline crew members routinely wear a radiation dosimeter to monitor the amount of radiation they are exposed to. 100% of the crew members surveyed supported the idea while 69% of the passengers surveyed were also on board.

These findings then spur the following questions… How much dose do you actually get from flying and based on these findings, should airline crew members be considered occupationally exposed and therefore need to wear radiation dosimeters?

To answer the first question, during a recent trip from Toronto (YYZ) to Tokyo (NRT), (with a layover in Vancouver), equivalent doses were measured using an EPD (DMC 2000 XB, MGP Instruments, Arrow-Tech, ND, USA). The doses are list in Table 1.

Table 1: Measured doses received on Air Canada flights from YYZ to NRT

Direction	Flight Numbers	Total Deep Dose	Total Shallow Dose	Time	Cruising Altitude
YYZ→NRT	AC 105, AC 3	14 µSv	19 µSv	14 hrs	~ 37,000 m
NRT→YYZ	AC 102, AC 4	12 µSv	15 µSv	12.5 hrs	~ 37,000 m

So what does this mean? Is this a lot? To put this into perspective, a typical chest x-ray gives a dose of approximately 30 µSv in Canada.[15] This means that a return flight from Toronto to Tokyo is like getting 1 chest x-ray. Please note: measurements were taken with TLD chips for various readings, but unfortunately the readings were not returned in time for this report.

Next question: Should airline crew members be considered occupationally exposed? Mathematically, this is a simple question. There is a limit on the amount of radiation people are allowed to be exposed to over and above the background dose. For the general public, this limit is 1 mSv/year and for nuclear energy workers the limit is 20 mSv averaged over 5 years with no more than 50 mSv in any one year. (ICRP) If the average flight attendant works about 85 hours/month[16]**,** 12 months a year, and flies between Toronto and Tokyo each time, then he/she would get exposed to approximately 1.4 mSv in a year. Now this is a very crude estimate but it does suggest that flight attendants could possibly be considered occupationally exposed workers.

There have been other studies that investigated this very question. These studies were much more in depth, so their values are different. For example, a study was conducted by the Royal Military College (RMC) and the Air Canada Pilots Association (ACPA) in 1999 and 2000 which followed 11 Air Canada flight numbers. The flights included both international and domestic destinations. Doses were measured on two, three or four trips for each flight number. The exciting news is that one of the flights they measured was the same as the flight taken on the recent trip to Japan, flight AC 105 from Toronto to Vancouver. We measured a total Dose Equivalent of 4 μSv while the RMC study reported a dose equivalent of 30 ± 5 μSv**.**[17] The reason for such a big difference was the way the doses were measured. The RMC measured the absorbed doses using a Tissue Equivalent Proportional Counter. This detector is much more sensitive and can measure not only gammas and x-rays, but also neutrons (which are not measured by the EPD.) The RMC was also able to measure their own Q factor value which they found to be 2.2 to 2.4 for all flights.[17] To get the Dose Equivalent, the absorbed dose was multiplied by the Q factor. The Q factor value was assumed to be 1 for the EPD used in our experiment as it only measured a dose from gamma and x-rays. This Q factor difference alone accounts for the RMC's dose being at least twice as much as our measured dose. Other contributors to the difference in equivalent dose measurements could be changes in altitude while flying, solar flare ups or storms, and changes in latitude.

Now, let's calculate the annual dose for a flight attendant flying only between YYZ and YVR. For the sake of convenience, assume the dose is the same in both directions, the average number of hours worked in one month is 85 and the flight attendant works 12 months a year. Based on our measurements, the annual dose would be 0.8 mSv and based on the value reported by the RMC and the ACPA, the annual dose would be 6.12 mSv. Now keep in mind, our measurements are not that accurate. The RMC's values are more realistic. 6.12 mSv is significantly more than the ICRP's limit of 1mSv for the general public What really drives the nail in the coffin is the fact that the average occupational dose received by nuclear energy workers in 2004 in the United States was 1.6 mSv[18] and was 0.3 mSv in Canada[19]. Based on these numbers, flight attendants and pilots get quite the occupational dose and yet are not considered occupationally exposed and are not even informed by their employers about the possible risks of being exposed.

But, the more important question here is, do these doses have any effect on our health? This has been a question of focus in the radiation sciences world for decades and has not been entirely answered. The doses reported in this essay are very low with respect to atomic bomb survivors and radiation therapy patients. Some scientists feel that the smallest doses can cause harm, while there is some convincing evidence that small doses can actually impose positive side effects. In terms of health effects, as mentioned earlier, there have been a variety of studies conducted. A study done in 2001 by Nicholas et al showed that among commercial airline pilots, there was an increase in melanoma, neuron disease and cataracts, but other disease were lower than the US population average.[20] That same year, a study by Haldorsen et al in Norway also found an increase in skin cancer among cabin crew but they did not attribute the cause to occupational exposure, but more to a lifestyle.[21] 2001 must have been a busy year in the airline industry because also in that year, a study in Iceland by Rafnsson et al found an increase in breast cancer among female flight attendants[22]. In response to findings like these, a study was conducted in 2005 by Kojo et al in Finland and they found that an increased breast cancer frequency is most likely not due to occupational exposure but more likely due to family history[23]. These findings show that there is not a big difference in cancer frequency between crew members and the general public.

From the findings of this investigation, as well as the finding of other studies, it can be seen that airline crew members do receive a significant dose over and above that of background radiation on earth. Since their doses are even more than that of a typical nuclear energy worker, who by law must wear a personal dosimeter, it only makes sense to have pilots and flight attendants wear personal dosimeters as well. The sole contributor to cosmic radiation is from the sun and other stars. These are sources that are totally out of human control. At any given time, there can be a solar flare up or storm and no one would even know about. For the safety of the crew, as well as the public, it only makes sense to wear dosimeters. And as one last caveat, this would also be in the interest of the scientific community. Since there is no real-life data of low doses on humans and no ethics committee would ever allow a study on humans, it would be very beneficial to have airline crew members wear dosimeters to improve our knowledge of low doses and their effects on human health. Maybe once and for all we can end the debate on the linear no threshold model.

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