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Female Cabin Crew Radiation Exposure and Cancer Development: A Cross-Study Inquiry

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Abstract

While a number of studies have investigated the exposure of female aviation cabin crew members to cosmic radiation during their lifetime, each is limited in scope and geographic location. To better determine the overall impact of radiation on cabin crew staff, this study analyzed the results of multiple previous studies. The purpose of this research was to determine the role of low-dose radiation exposure in female crewmember cancer development by statistically analyzing the test results of five independent quantitative studies regarding cancer development among crewmembers. While some studies had revealed statistically significant evidence that cosmic radiation exposure did lead to cancer, other studies found that flight crew rates of cancer were within the same range as the general population. The current study was analyzed both invasive breast and total cancer cases. A Chi-Square goodness-of-fit test was utilized to analyze the five study data sets and thereby provided a comparison of observed invasive breast and other types of cancer in female flight crew with the expected rates for invasive breast cancer in the general population. For breast cancer, the results indicated that these crewmembers had a higher incidence of this type of cancer about the relevant populations from which they came, $\chi^2(4, n = 175) = 19.79, p < .001$. The findings for all types of cancer types was higher for crewmembers, but such differences were not statistically significant, $\chi^2(4, n = 175) = 5.25, p = .237$. Standard Incidence Ratios (SIR) were also compared reviewed indicating $M = 1.394 (SD = .287)$ for breast cancer and $M = 1.066 (SD = .168)$ for all cancer types.

Keywords: cancer, aviation, airline, crew, exposure, radiation

Scientists have known about and have actively studied radiological activity for over a century. In settings of gross proportion, mass radiation exposure can lead to loss of life or total mutation of living organisms, but in other more controlled settings, radiation therapy has been used as a cure for certain types of illnesses (Friedberg & Copeland, 2003). While high doses and monitored medical exposures to radiation are relatively well understood, knowledge about how radiation affects the human body during periods of low-dose, repetitive exposure in an occupational setting is still relatively lacking. Such exposure patterns are common among flight crewmembers.

Much data has been collected via cohort studies of flight crew throughout the course of their career and their likelihood, versus the general population, of developing certain health problems. Development of carcinogenic cancer is strongly suspected of being linked to mild radiation exposure. Numerous epidemiological studies have shown increased cancer rates for those working closely with ionizing radiation in laboratory settings and for those living at higher altitudes with increased levels of background radiation (Ballard, Lagorio, De Angelis, & Verdecchia, 2000; Lin et al., 2012; Pearce et al., 2012). In particular, female flight crew face an elevated risk, some 30% higher, of breast cancer compared to the general population (Reynolds, Cone, Layefsky, Goldberg & Hurley, 2003). While confounding variables such as reproductive factors, circadian rhythm disruption, and lifestyle choices do influence cancer development, cosmic radiation exposure may be a contributing cause (Friedberg & Copeland, 2003).

Breast cancer is of particular concern as it comprises the largest percentage, about 16%, of cancers detected in women. In 2008, an estimated 458,000 women died from breast cancer worldwide, and the number of reported cases is growing on a yearly basis up to 1.5 million in 2012, even in low-income countries where numbers have traditionally been lower. While it is not known how many of these cases are linked to radiation exposure, research continues to show increased likelihood of breast cancer development as countries adopt Western practices (World Health Organization [WHO], 2013). This increase in cancer cases in developing countries may also be attributed to increased reporting and diagnoses. However, other factors of societal shifts should not be ruled out as a contributing cause. Since commercial aviation is a newer factor in these areas, it could be considered one of many influences that are causing escalating cancer risk (Ballard et al., 2000).

Literature Review

Understanding Ionizing Radiation

Ionizing radiation is an ordinary part of life that is unavoidable as radioactive material makes up everything from the ground we walk on to the matter that makes up our bodies. Non-ionizing radiation, such as used in microwave technology or radio waves, causes atoms to vibrate and can create thermal energy, however, molecules are relatively stable and therefore do not lose electrons meaning safety risk is minimal. Contrarily, ionizing radiation is unstable, causing atoms to lose electrons thereby creating excess positive and negative ions through intense vibration. These extra ions produce a significant

amount of energy in a small space and can have damaging effects in too large a dose on the human body (Environmental Protection Agency [EPA], 2015).

Many types of ionizing radiation are known such as ultraviolet (UV), gamma, X-rays and infrared light, each being classified based on the amount of energy they contain and the type of ions they carry. In particular, cosmic ionizing radiation is the result of exploding stars whose energy travels light years towards earth and exists in large doses outside of the earth's atmosphere. It is distinctly different from other types of ionizing radiation due to its containing 50% neutrons. How these neutrons change and alter atoms in the human body is still undetermined, and further research is being conducted. When elevation exceeds 20,000 feet above sea level, the Earth's magnetic field and atmosphere do not provide coverage against ionizing radiation as they do on the ground, which puts flight crew at risk every time they fly above that altitude (Seabridge & Morgan, 2010).

Radiation exposure is typically measured in Sieverts (Sv), which is a large amount of radiation that would only be encountered in a nuclear power plant meltdown or after an atomic bomb. More commonly, radiation doses are seen in millisieverts (mSv), one thousandth of a Sievert, and in microsieverts (μ Sv), merely one millionth of a Sievert (Blue, 2000). Encountering radiation on a regular basis is unavoidable as around 14% of the human body's tissue comprises radioactive material and another 68% of annual radon exposure is inhaled in the air we breathe. The remaining 18% of exposure comes from cosmic radiation, such as that faced in increased dose by the flight crew, and building materials or soil. Just sleeping next to another person for one night can increase radiation exposure by .05 microsieverts (Lee, 2011). Typically, a person would receive about 24mSv of radiation per year, and only about .27mSv of that would come from cosmic radiation. However, an average crew member would receive an additional 20mSv of cosmic or background radiation per year (Blue, 2000).

Governmental Action

In 1994, the Federal Aviation Administration (FAA) formally stated that flight crews are occupationally exposed to increased health risk due to encountering ionizing radiation on a consistent basis and that employers should work to educate flight crew on these risks (FAA, 1994). This labeling of occupational exposure qualifies flight attendants and pilots to be classified as "radiation workers," the same classification used for workers in nuclear power plants, however, unlike nuclear workers no documentation is required in the US to monitor flight crew exposure levels. The FAA does administer a website to aid flight crews in monitoring radiation exposure which has a "Radiation Received in Flight" counter that any user can enter their flight routes and altitudes on a day-to-day basis to see accurate information (FAA Office of Aerospace Medicine, n.d.).

While no amount of radiation exposure is considered a safe level, the FAA currently recommends that US flight personnel be exposed to no more than an additional 20mSv of radiation per year based on a five-year average or more than 50mSv in one years time (Friedberg & Copeland, 2003). For the average crewmember working approximately

1000 flight hours annually, it would be unlikely to even reach the 20mSv average increase in dose. However, it is possible that a crewmember flying extreme hours or frequent long distance flights could exceed recommended limits. Even still these numbers are a recommendation and not a law. For pregnant women, the International Commission on Radiological Protection (ICRP) recommends no more than 2mSv of exposure for the entire pregnancy, but the National Council on Radiological Protection (NCRP) suggests no more than 5mSV. Using these guidelines, it would be at the discretion of the employee to decide how much she should risk (Blue, 2000).

The European Union has gone a step further enacting legislation that set up basic safety standards mandating airlines to keep records of aircrew radiation exposure and limiting annual levels to no more than 20mSv, except in the case of pregnant crew members that are allowed no more than 1mSv since fetuses have been identified as being particularly vulnerable to their development (European Commission, 2009). This law, which varies in enforcement by country, requires that documentation is kept of employee's radiation exposure level even after termination of employment and in some cases even after the employee's death. Yearly classes must be administered to educate flight crew on radiation risks, and pregnant women must give notice as soon as possible of their pregnancy so that their schedule can be altered according to the guidance of the law to not exceed the 1mSv exposure limit. Some countries have even limited pregnant flight attendants to only three months of active flying before requiring either ground-based work or leave of absence (European Commission, 2009). While the US and Europe have chosen different paths of enforcement and legality, the severity of radiation exposure remains an area of concern for both parts of the world.

Environmental Awareness

Environmentally, there are four main factors that affect flight crew radiation exposure levels: altitude, latitude, airborne hours, and solar activity. Even at sea level on Earth, there is background radiation present and radon in the air that is breathed. For every 6,000 feet increase in altitude from Earth, cosmic radiation levels double as atmospheric coverage becomes thinner. Because the particles in radiation are electrically charged, the magnetic field of the Earth deflects most particle activity, but as aircraft increase in altitude that protective shield becomes weaker causing increased exposure. Typical radiation exposure received on a commercial airliner flight would equate to about 100 times the amount of background radiation experienced on the ground at sea level (European Commission, 2009). Of particular concern are private jet or military pilots who fly unprotected at altitudes around 50,000 feet and have no limits on duty time, they are at foremost risk for radiation exposure (Blue, 2000). Furthermore, up-and-coming commercial spaceflight will need to assess the risks of radiation exposure at altitudes untested for increased periods of time, as this will become an even greater concern for crewmembers and passengers.

Latitude is another major factor in the level of exposure. At the equator, coverage of the atmosphere and magnetic pull of the Earth is the highest resulting in minimal levels

of background radiation. As distance grows further from the equator, the thinner the atmospheric coverage and the greater the risk of exposure. Due to this aircraft flying at altitudes of 30 to 40,000 feet around Iceland acquire more radiation exposure than one flying around Peru. As an airplane flies closer to the Earth's poles, atmospheric protection decreases (Finneran, 2011). This has become more concerning as airlines have begun to favor polar routes for efficiency on certain long distance routes (Boeing, 2014). Scientists who have observed 10 times the amount of traffic over the poles than they did back in 1999 are advocating for greater space weather awareness and installed meters in the cockpit to help monitor solar activity. Interestingly, the magnetic poles of the Earth have been shifting southward approximately 40 miles per year, as they are different than 'true north,' which always stays the same. As the poles shift further south, crews will increasingly encounter more radiation exposure (Finneran, 2011).

The number of hours flown and also bursts of solar activity also affect the environment in commercial aviation. Employees that fly more than the estimated 1,000 hours a year or work for longer durations at a time on long-haul international routes may also be increasing risk factors for cancer development. While bursts of major solar activity can sometimes be predicted, such as the 11-year solar cycles of the sun when Coronal Mass Ejections create solar flares on Earth, at times other more random bursts of energy and magnetic activity could threaten aircraft (Blue, 2000). During a solar storm, a person flying over the North Pole could receive almost the entire year's worth of radiation exposure in just one segment (Finneran, 2011). Since this is an area of growing concern, it may be prudent for aircraft manufacturers to take into consideration future space weather systems on aircraft.

Aviation stakeholders and cancer scientists have joined efforts by way of helping researchers conduct independent, epidemiological studies of commercial pilots and flight attendants, private charter jet employees, and military personnel to try and assess and quantify the health effects of radiation exposure in the air. Some studies have and are currently being produced that analyze cancer data of flight crewmembers against that of the general population and compare what types of cancer are most common among them as well as suspected causes. Some of these studies have focused solely on the military, while others have focused on pilots or flight attendants in particular since they not only are exposed to increased levels of cosmic radiation but also electromagnetic radiation from sitting long hours in or near the cockpit and encounter jet fuel emissions on a daily basis. What research has found is that cancers of the prostate, thyroid, upper respiratory, gastric tract, liver, and breast are particularly elevated, and malignant melanoma skin cancer is notably prevalent among all in-flight personnel working more than five years (Linnersjo, Hammar, Dammstrom, Johansson, & Eliasch, 2003). Table 1 below shows the increased difference in cancer development at varying levels of ionizing radiation exposure.

Of particular concern is the rate of breast cancer development among female flight attendants. Tokumaru et al. (2006) found up to a 40% increase in breast cancer among female flight attendants versus the general population. Many other studies have been done in the United States and throughout Europe that classify the types of cancer, whether 'in

situ' (benign) or as 'invasive' and the mortality level associated with the breast cancer in each location. While results have widely differed, one study in Finland showing no difference at all between crew and the general population, the majority of the studies conclude that there is significant evidence that breast cancer among crewmembers is statistically significant and that it is a growing concern (Kojo, Pukkala, & Auvinen, 2005). Part of the discrepancy in study data is that there have been limitations in the studies due to the inconsistencies in small sample sizes, differing techniques of narrowing heterogeneous factors or more complexly, the differing levels of ionizing radiation during the tested time period (Tokumaru et al, 2006). Linnertsjo et al. (2003) state the increased importance further clarifying this study data: "the possible excess of breast cancer among female cabin crew and the lack of a consistent pattern in previous epidemiological studies makes it necessary to provide additional data on the cancer incidence in this group" (para. 3). As more studies become available these individual study limitations should less profound and the results more conclusive.

Table 1
Increased cancer risk based on mSv of radiation received

mSv	Risk	mSv	Risk	mSv	Risk
2	1 in 13000 (0.008%)	20	1 in 1300 (0.08%)	120	1 in 210 (0.5%)
3	1 in 8300 (0.01%)	30	1 in 830 (.1%)	140	1 in 180 (0.6%)
4	1 in 6300 (0.02%)	40	1 in 630 (.2%)	160	1 in 160 (0.6%)
5	1 in 5000 (0.02%)	50	1 in 500 (.2%)	180	1 in 140 (0.7%)
6	1 in 4200 (0.02%)	60	1 in 420 (.2%)	200	1 in 130 (0.8%)
7	1 in 3600 (0.03%)	70	1 in 360 (.3%)	225	1 in 110 (0.9%)
8	1 in 3100 (0.03%)	80	1 in 310 (.3%)	250	1 in 100 (1.0%)
9	1 in 2800 (0.04%)	90	1 in 280 (.4%)	275	1 in 91 (1.1%)
10	1 in 2500 (0.04%)	100	1 in 250 (.4%)	300	1 in 83 (1.2%)

Method

Purpose

The goal of this study was to analyze and compare the data within five independent scholarly studies that focused on breast and total cancer rates in female cabin crew. The studies that were chosen were completed in the countries of Sweden, Norway, Finland, Germany, and the United States. The reason for choosing these particular studies was in part because of the necessary comparisons between the estimated national ratios for breast cancer development for that country and the observed data obtained through surveys of local flight crew (Ballard et al., 2000). Also, these studies contained either Standard

Incidence Ratio (SIR)¹ or Standard Mortality Ratio (SMR)² for breast cancer rates, which helped to homogenize differ data types and exclude studies that were not narrow enough to show 95% confidence intervals for breast cancer data. This particular combined set had also never been used before in a published analysis thereby making it unique in its findings.

Hypotheses

Both aspects of this study were guided by the following research hypotheses:

- H₀: The distribution of observed and expected invasive cancer of crew members was not statistically significantly different than the general population.
- H_a: The distribution of observed and expected invasive cancer of crew members was significantly different than the general population.

Data Collection and Application

Data were collected from each of the five studies to extract the estimated breast and total cancer incidence rates in each of the countries (each country tabulated their rate of invasive breast cancer since rates vary by region) and then the actual data they collected from the surveys of flight crew. Altogether, 29,654 women were included from the five studies with the largest amount being 16,014 from Lufthansa Airlines in Germany, 3,144 from Norway, 1,577 from Finland, 2,324 from Sweden, and 6,895 women from the state of California in the United States.

For each study in this analysis, data were collected from the selected female flight attendant cohort according to a specified number of years of employment at their company and compared against cancer data the researchers were able to obtain from the national cancer database in each country. In Sweden, the data came from Scandinavian Airline System (SAS) and included the years 1961 to 1996, and took into account dates of employment and longevity of crewmembers at the company (Linnertsjo et al., 2003). In Finland, the data were collected from the period 1967-1992 from a cohort at Finnair Flight Company and used three sets of age ranges to further narrow the data to what age range was affected by the breast cancer (Pukkala, Auvinen, & Wahlberg, 1995). Norwegian data were collected from their national Civil Aviation Administration which licenses flight crew and keeps track of their employment dates. Norway had the longest study range from 1950 to 1994 (Haldorsen, Reitan & Tveten, 2001). The German study collected data stored by the airline Lufthansa or their national LTU International Airways and included the years 1960 to 1997. The German study was different in their methodology from the others in that they studied mortality rather than incidence rate, but still yielded data including invasive breast cancer against the general population (Blettner, Zeeb, Langer, Hammer & Schafft, 2002). The US study included flight attendants that were part of the Association of Flight

¹ SIR = (Observed Cases/Expected Cases) x 100

² SMR = Observed Cases/Expected Cases

Attendants (AFA) and resided in the state of California between the years of 1988-1995 (AFA, 2007; Reynolds et al., 2003).

While each of the five studies varied in the number of years chosen for analysis, the data that was obtained were compared only against that set of respective years in the cancer database for that country to create an accurate representation of cancer rates for that given time period. For instance, when taking into account female flight attendants employed in the 1960s who developed breast cancer, that data were only compared with the national rate of breast cancer for that country in the 1960s. This avoids the confounding variable of time as well as medical reporting in that country and cancer rates specific to that area of the world.

All of the test studies were measured against national (or in the case of California, state) statistics registries for *invasive* cases of breast and total cancers. *In situ* (identified cancer that has not turned into a tumor) breast cancer cases were not taken into account for this analysis. A well-documented study from Iceland was not taken into account in this analysis due to the lack of comparative observed versus expected statistical data that was not included in the published study (Rafnsson, Sulem, Tulinius, Hrafnkelsson, 2002).

Results

Chi-Square Results

Statistical calculations for the Chi-Square Goodness-of-Fit test were conducted to determine if the observed frequencies were different than total local population expected frequencies. In the case of breast cancer, the results were found to be statistically significant, $\chi^2(4, n = 175) = 19.79, p < .001$. Therefore, there is high confidence that flight crew invasive breast cancer rates are greater than the rate of invasive breast cancer among the general population. While some the studies attempted to pinpoint the cause of higher rates of low-dose radiation exposure, they were not able to entirely isolate confounding variables to rule out family genetics and lifestyle factors. However, low-dose radiation exposure is highly suspected as a contributing cause since that is one of the primary differences between flight crew lifestyle and the general population.

In order to evaluate overall cancer risks among those sampled in the utilized studies, a Chi-Square Goodness-of-Fit test was conducted utilizing the overall cancer incidence of crewmembers vis a vis the population values. The findings of this analysis were not statistically significant $\chi^2(4, n = 175) = 5.25, p = .237$.

Comparative Analysis of Results

All five of the studies showed higher than average levels of invasive breast cancer among flight crew which was further explored via Chi-Square analysis and gives statistical credibility through a greater sample size. The results of each national study on its own are sufficient, but when looked at as a grouped international study, comparative cancer rates

at different locations from the equator can be determined. This also provides insights on a more global scale and across varied populations and samples.

Each country had expected values based on the national cancer registry for that country during the years of the study and observed values based on the female flight attendant surveys. Table 2 and Figure 1 outline the raw data of expected and observed values for each country's study. Interestingly, despite the differing amount of years for each study, rates for the expected and observed data were similar in size throughout Europe reflecting the growing detection of cancer as decades progressed. The data for the state of California in the US initially appears to have significantly more invasive breast cancer cases than all of the other studies particularly as it had the smallest number of study years. However, this can be attributed to the large sample size and advancing detection methods in the late 1980s and early 1990s. California's data does present interesting findings as breast cancer rates among flight crew are so elevated compared with the levels of the general population.

Figure 1 clearly displays the magnitude of different outcomes between countries. While the data for California does indicate a cause for concern when viewed comparatively with the other four countries, its expected rate is also higher than any of the other countries. This also could be due to the larger sample size of the study compared with Norway, Finland, and Sweden. The results for Germany with the largest sample size of over 16,000 can be seen as very low rates overall, however, this also was just for mortality from the invasive breast cancer and not just incidence rates. If incidence rates were included in these statistics, the rates for Germany would certainly increase as not everyone who develops invasive breast cancer falls victim to it.

The case study in Norway proved to be the least significant of the studies with the smallest difference in expected and observed outcomes. Given Norway's proximity to the north polar region, it surprises its countries invasive breast cancer rates were so low. This was the only study out of five that concluded that their results were not significant overall for all cancer types due to ionizing radiation exposure and found that differences in cancer statistics were due to lifestyle choices of crewmembers (Haldorsen et al., 2001). Lastly, Finland's study proves to be significant statistically but has more recently been redone to show less significant results. The follow-up study done by Kojo et al. (2005) was not included in this analysis because the specific parameters they measured in incremental years of employment and age did not yield observed or expected outcomes and the data did not match in methodology with the other studies included in this analysis. The results of this follow-up study in Finland determined that higher rates of breast cancer among female flight attendants were due to lifestyle factors and not specifically ionizing radiation exposure (Kojo et al., 2005).

The findings of the overall cancer incidence analysis perhaps place some doubts in the fact that crewmembers are, in general, more likely to develop cancer. However, the general level of incidence appears slightly higher, albeit not significantly so. This data is outlined in Table 3 and Figure 2. This data does cause some concern about the overall

cancer rates in both the U.S. and in Norway which are noticeably higher than in other regions.

Table 2
Raw Data of Observed Invasive Breast Cancer Rate versus Expected Rate by Count

Country	Years	Observed	Expected	Study Size	SIR (Confidence)
Germany	1960-1997	23.7	18.5	16,014	1.28 (.72-2.20)
USA	1988-1995	60	42.17	6,895	1.42 (1.09-1.83)
Norway	1950-1994	38	34	3,144	1.1 (.8-1.5)
Finland	1967-1992	20	10.7	1,577	1.87 (1.15-2.23)
Sweden	1961-1996	33	25.45	2,324	1.3 (.85-1.74)

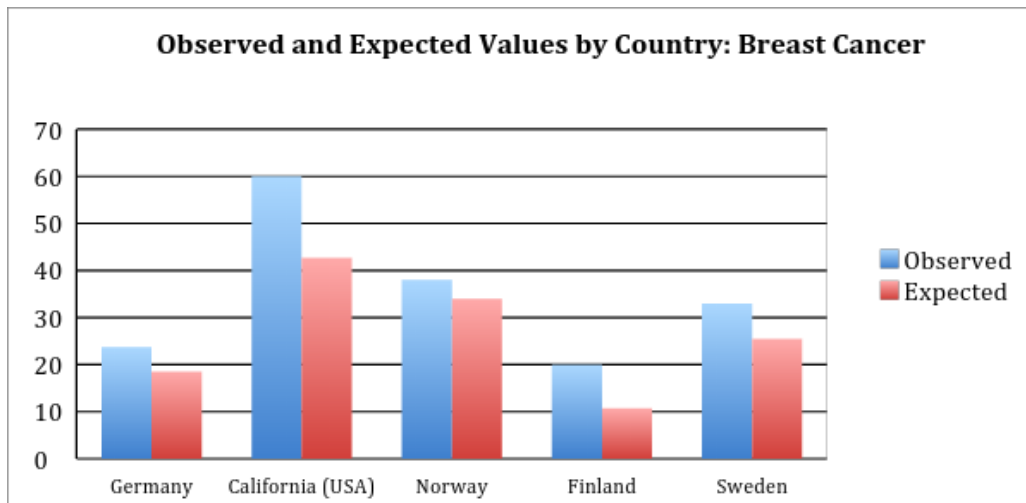


Figure 1. Bar Graph Comparison of Raw Data: Breast Cancer

Data Confidence and Study Significance

As illustrated in Figure 3, one of the main factors the researchers in all five studies utilized was the SIR of observed and expected outcomes to determine overall confidence and study significance amongst other studies. It can be seen that all the studies yielded around the same comparative value, none exceeding 2.0 in actual value and none lower than 1.0. Since all these SIR values were positive (greater than 0) to begin with, they all proved significant when compared with the general population. The highest of these values

was Finland with 1.87 SIR level, and the lowest value was Norway with a SIR value of 1.1. When a mean is taken of this data, the result is $M = 1.394$ ($SD = .287$). Overall the results paired very similarly contributing to Germany, Norway and Sweden having lower rates about the mean and California and Finland having higher rates. While all these statistics point to increased invasive breast cancer rates among female flight attendants, non-ionizing radiation still cannot be attributed as a cause unless other confounding variables can be ruled out.

While the original data for the expected outcome was listed with a national rate of the number of invasive breast cancers per 100,000 people, statistical linear regression formulas were used in each study to calculate expected values comparatively to the number of the individuals in each cohort. Some data such as the primary invasive breast cancer statistics from Norway before 1953 were unobtainable. The raw data in each study helps to give greater perspective and insight to the expanse of invasive breast cancer on a national level rather than narrowing them down into statistics only relevant to each study. These results as well as other meta-analyses have certainly shown significant results and prompted more questions within the medical and scientific community.

Table 3
Raw Data of Observed Total Cancer Rate versus Expected Rate by Count

Country	Years	Observed	Expected	Study Size	SIR (Confidence)
Germany	1960-1997	54.9	69.2	16,014	0.79 (.54-1.17)
USA	1988-1995	104	99.25	6,895	1.05 (.86-1.27)
Norway	1950-1994	127	117.3	3,144	1.1 (.9-1.7)
Finland	1967-1992	35	28.4	1,577	1.23 (.86-1.71)
Sweden	1961-1996	76	75.27	2,324	1.16 (.76-1.55)

Figure 4 shows the SIR of observed and expected outcomes to determine confidence and study significance amongst other studies regarding total cancer incidence. The overall cancer SIR values are lower and, except Germany, were higher than 1.0. The mean value across studies was $M = 1.066$ ($SD = .168$). Overall the results paired very similarly contributing among all countries except Germany. Again, non-ionizing radiation still cannot be attributed as a cause unless other confounding variables can be ruled out.

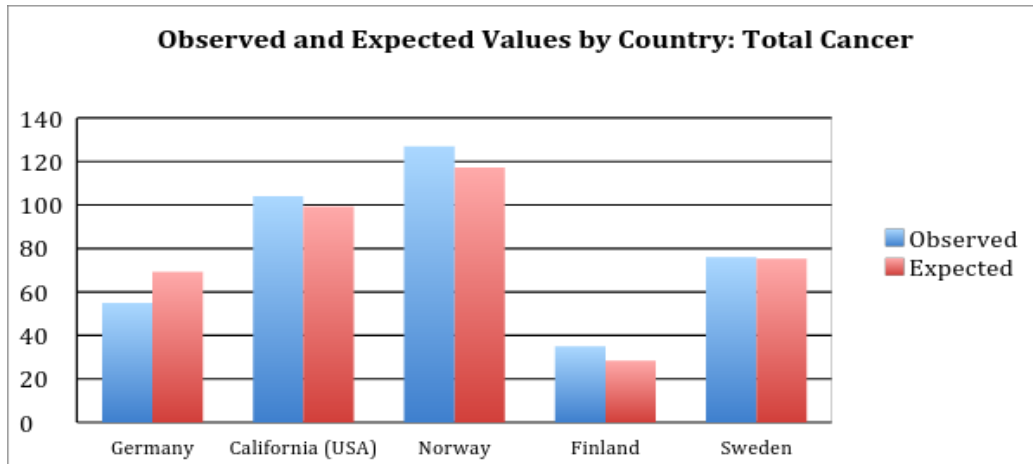


Figure 2. Bar Graph Comparison of Raw Data: Total Cancers

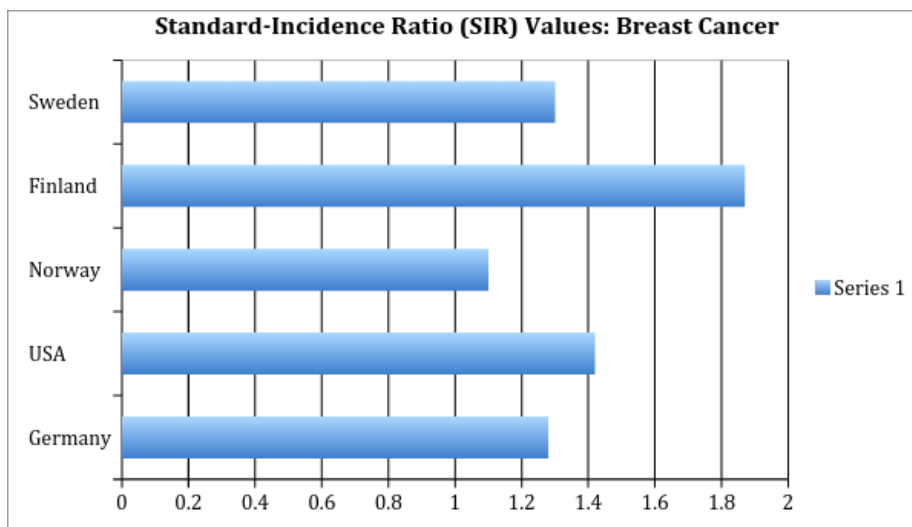


Figure 3. Standardized-Incidence Ratios: Breast Cancer by Country

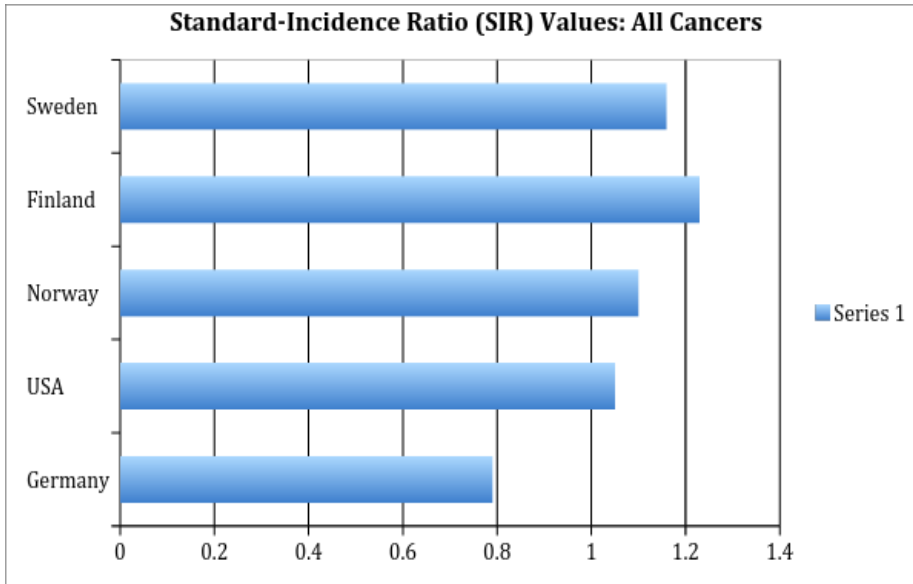


Figure 4. Standardized-Incidence Ratios: All Cancers by Country

Discussion

Human Limitations: Genetic Predisposition and Socioeconomic Factors

Within the realm of human experience and advancement have always come limitations, setbacks and a need for further research to overcome problems. However, no challenge has presented itself quite like cancer. Cancer will affect about half the men in the United States and about one-third of the women (American Cancer Society, 2014). Questions have arisen such as why certain areas, such as the breast, are particularly susceptible to cancer in-flight crewmembers and how much of that risk can be attributed to cosmic radiation in particular. According to Wakeford (2004) that some tissues are more prone to exposure than others, which is suspected due to the weight of tissue at the site. Breasts contain a great level of soft tissue which is light in weight and density giving them a relatively high risk for exposure (Pukkala, Auvinen, & Wahlberg, 1995). This explanation of tissue density also explains the greater risk of male flight crewmembers to develop prostate cancer as this has also been linked heavily to ionizing radiation exposure. While researchers have become aware that this lightweight tissue is more susceptible to radiation, it is a natural limitation of the human body and techniques, and preventative methods could be implemented in the future to protect more sensitive areas prone to cancer development.

One limitation that is out of the control of aviation companies, employees, and even the government is simply the genetic propensity for developing cancer. No matter what career path, lifestyle choices or area of the world people choose to live in, cancer potential is located with our human DNA and can still act as an uncontrolled growth within

the body which can rapidly or slowly spread to vital organs. Tests can be conducted to identify specific mutation types within the DNA, family history of cancers, physical examinations and medical history, which all may indicate a likelihood of developing cancer in the future (National Cancer Institute, 2013).

Some studies have indicated that socioeconomic class can affect certain types of cancer growth; particularly lung cancer and cervical cancer have been linked to poorer classes while breast cancer and melanoma are diseases of the wealthier populations. The link between lung cancer and poverty are clearer since around 80% of lung cancer cases can be attributed to smoking. While many affluent individuals have stopped smoking, lower classes are still more likely to take up smoking or be around second-hand smoke. The cancers of the wealthier populations, such as breast cancer, have been linked to the wealthy having fewer children and waiting until later in life to have their first child (Medical News Today, 2008). These factors affect flight crew cancer populations as well since the majority of airline employees come from areas of the world wealthy enough to support a commercial aviation operation. Limitations such as this do affect operations, but airlines have little to no control over the genetic and social class backgrounds of their employees.

Human Behavior: Reproductive and Lifestyle Factors

One area of crewmember behavior that is highly suspected as a link to breast cancer prevalence is their reproductive choices. Female crewmembers typically wait until later in life than the average women to become pregnant. Also, they are less likely to have multiple children (especially more than three) and more likely to choose not to have children at all (Raffinson et al., 2003). As depicted in Chart 6 below, the Swedish study, Linnertsjo et al. (2003) found that the rate of female flight crewmembers under the age of 25 that had a child was only 7% compared to the average population rate of 51% of all Swedish women. It is estimated that from a Nordic meta-analysis that this difference in reproduction age adds a 10% estimated increase in breast cancer incidence, which was consistent with the 1.1 SIR rate found by the Swedish study (Linnertsjo et al., 2003).

Similarly, the study Finnish study found that reproductive factors were more influential on cancer incidence than other factors (e.g. socioeconomics) (Pukkala et al., 1995). It is estimated that for every five years a woman waits to have children, the relative risk for breast cancer development increases by 20-30%, but that that risk can be decreased by having three or more children. Since only 28% of flight crewmembers were found to have three or more children, this gives further evidence of their increased cancer risk in addition to their tendency of later-life reproduction (Pukkala et al., 1995).

Since so many occurrences of breast cancer had been linked to flight crew reproduction, a study conducted in Iceland focused specifically on this issue of reproductive factors among crewmembers to attempt to isolate the variable based on length of employment, reproductive history, and quantity of children. Using conditional logistic regression, odds ratios were developed to track how long the employee had been a

crewmember before giving birth to their first child, how long a period she continued work at the airline after giving birth and whether she developed breast cancer. However, the results found that there was no specific link to breast cancer and age of reproduction (Raffnson et al., 2003). This study concluded that the increased rates were due to cosmic radiation exposure and jetlag more than the reproductive history of the woman.

Other lifestyle factors may also be considered a confounding variable in finding a cause for increased breast cancer rates. Alcohol consumption has been linked to playing a role in breast cancer development. In a study of flight crewmember lifestyle factors in relation to breast cancer prevalence, Kojo et al. found that there did seem to be an association between crewmember alcohol intake levels and their likelihood of breast cancer with an odds ratio of 4.11 and 95% confidence (Kojo et al., 2005). Alcohol consumption in women has been shown to increase by 7% per alcoholic drink per day in moderate drinkers, possibly due to increasing estrogen levels in the body (Key, Allen, Spencer & Travis, 2003). While not all crewmembers may indulge in drinking alcohol, it does seem to carry a high industry-wide prevalence in aviation careers. Other lifestyle factors that may increase cancer risk are frequent intake of jet fuel fumes and emissions and pesticides used in aircraft cleaning, although no studies have been done to specifically measure risk factors between emissions and pesticides or a comparison to workers who jobs primarily administer them on aircraft (Blettner et al., 2002). Overall, crewmember behaviors of postponement in reproduction and their tendency for moderate alcohol intake do increase their risk of breast cancer development.

Circadian Rhythm Disruption and Increased Radiation Exposure

Some increased cancer incidence can be attributed to natural limitations of the human body and some of the lifestyle choices and behaviors of flight crew; other factors are more controllable and could be better regulated. One of the most widely researched causes for breast cancer is swing-shift work or regarding human factors, circadian rhythm disruption. Chronic interruptions in circadian rhythm and frequent jet lag from flight crews working varying shifts, often at night and across numerous time zones decreases melatonin, a natural hormone produced during sleep. Melatonin production is seen as a natural anti-estrogen by decreasing estrogen receptor in the bloodstream and thereby aiding in the prevention of breast cancer cells developing. Also, it decreases the harmful effects of tamoxifen, an estrogen receptor that has been shown to act harmfully to human tissue (Mawson, 1998). Melatonin production, which is secreted into the body by the pineal gland, was found to be desynchronized in female flight attendants because of the disruption of circadian rhythm (Buja et al., 2006). This desynchronization or interruption of melatonin production could be a contributing factor in flight crew breast cancer cases.

While some flight crew may have control over elements of their schedule such as route and time of check-in, frequently little is done to prevent working long shifts into nighttime hours and redeye flights built into flight pairings. One shift may start at 0500 and the next day the crew member will be expected to work a redeye flight. Reserve flight crewmembers have no choice on time or routing of a trip. Since melatonin secretion occurs

naturally between the hours of 2100 and 0800, crewmembers are put at risk when they repeatedly break their sleep cycle to work (Mawson, 1998). Other studies outside the industry of aviation such as medicine or factory work that involve a swing shift for workers have also indicated increased risk of breast cancer for females providing further evidence that some of the risk factors may be linked to preventable scheduling concerns (Pukkala et al., 1995). Reliance on computer software designed only to schedule to contractual and FAA regulations for duty and rest periods may be leading to shifts that do not take into account a beneficial sleep to the employee. While it is important to have coverage and offer a wide variety of flight times, crewmember schedules should also take into account sleep rhythm to prevent unsafe acts in the air and harmful fatigue.

Radiation Variations

Another consideration that should be addressed, but is beyond the scope of this study, is the possibility that differences in cancer rates during the time periods outlined in previous studies coincided with different levels of Coronal Mass Ejections. In theory, times of heightened solar activity could account for coinciding elevated cancer rates.

Areas of for Future Research

As previously discussed, unnecessary ionizing radiation exposure may also be considered an unsafe act relating to human factors. It deserves stating that when studying effects on survivors of the atomic bomb that was dropped on Hiroshima and Nagasaki, researchers found that organs that are particularly at risk are the female breast, thyroid, and lung when exposed to more than 1 Sv of radiation, while other areas seem to be more resistant to radiation exposure such as uterus, rectum and pancreas (Wakeford, 2004). The association between atomic bomb victims who received a large dose of radiation all at once and the low-dose exposure levels of crewmembers is hard to compare, but notably, the types of cancer that develop prevalently among survivors and crew members are similar. Results produced greater than ordinary cases of leukemia within a few years after the bombing for survivors and while tumors did not immediately appear, after years of latency prevalent tumors among the affected group included thyroid, breast, lung and non-melanoma skin cancers. Through epidemiological inference, the comparisons with flight crew prevalent cancers may also be seen. This similarity in occupational exposure is also seen in radiologists and radiographers in leukemia development and hard rock miners of uranium and tin in lung cancer development (Wakeford, 2004). This serves as one of the most compelling pieces of evidence that ionizing radiation is increasing breast cancer: that the foremost atomic bomb cancer is exaggerated cases of breast cancer just as it is among flight crewmembers. While air carriers and the FAA have certainly not made an effort to cover up the increasing crewmember cancers, concerns for safety have certainly not been emphasized, showing a failure of safety related policies.

Additionally, global aerospace operations have already begun greater enhancements of radiation exposure prevention as astronauts are at a much higher risk spending increased periods of time in space and where linear energy transfer (LET) is much

greater than commercial airline operations. Limitations are already in place for a low-Earth orbit with men allowed 1500 mSv in their career and women allowed only 900 mSV due to women's increased cancer risk in the areas of breast, thyroid and ovary's. Missions such as the planned voyage to Mars will include an increased cancer risk from radiation taking levels from 20% risk to Earth to about a 24-54% lifetime development risk while in space (Barr, Bacal, Jones, & Hamilton, 2007). While many researchers continue to refute evidence that ionizing radiation is leading to cancer on commercial flights, the statistical cancer risk that NASA is indicating plus the preventative measures they take for their astronaut's health and safety suggest otherwise.

Conclusion

Research still continues whether flight crewmembers are occupationally at risk for developing cancer due to ionizing radiation. While roughly 20 published studies have been done since 1990, some focusing solely on female crewmember breast cancer and others examining commercial and military crew cancer rates as a whole, the factors of low-dose ionizing radiation are still being confounded with lifestyle factors of familial and socioeconomic background, alcohol abuse, circadian rhythm disruption and reproductive choices of crewmembers. While none of these factors can be singled out as the sole cause, it may be that crewmember lifestyle choices due produce a heightened cancer risk when all the factors are combined. Still, epidemiological comparison to other advanced ionizing radiation catastrophes such as atomic bombs and nuclear power plant malfunctions have shown that the same types of cancers developed among survivors are very similar to the prevalent types of cancers found in crewmembers.

The five studies were chosen in this analysis from the countries of Germany, Norway, Finland, Sweden, and the state of California within the United States all give conclusive individual evidence that invasive breast cancer rates are higher among female flight crew than the general population. This study further concludes that breast cancer rates among female crewmembers are higher than the rates of the general population. Contrarily, the findings of this study were unable to corroborate the fact that female crewmembers may be more prone to cancers of all types, overall. Although the incidence of all types of cancer was higher numerically, they did not differ at a statistically significant level. Certainly, this warrants the attention of future research but may suggest that the flight environment is not as harmful as some studies have reported.

As globalization continues and aviation becomes a more common means of travel, and in particular as travel to Asia becomes more prevalent, concern for polar routing, which exposes crews and passengers to reduced atmospheric coverage and doubled rates of radiological exposure will continue to be a concern. Furthermore, developments in the field of commercial space travel may put travelers at risk for ionizing radiation exposure levels that have never before experienced in large scale. Safety systems have not yet developed to the point of ensuring safety beyond the immediate present or post flight for health related concerns. New technological developments through materials sourcing and particle research as well as authoritative action from the FAA, the European Safety Commission

and airline management personnel regarding ionizing radiation risks should be expected. Continual monitoring of radiological activity on the human body and particular cancer formations should spur new informational programs to educate the general public and crewmembers to health risks associated with air travel.

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