Abstract
Radiation risks are estimated in a competing risk framework where age or time after exposure estimates of increased risks for cancer and circulatory diseases are folded with a probability to survive to a given age. The survival function, also called the life table, changes with calendar year, gender, smoking status and other demographic variables. An outstanding problem in risk estimation is the method of risk transfer between exposed populations and a second population where risks are to be transferred. Approaches used to transfer risks are based on: 1) Multiplicative risk transfer models - proportional to background disease rates. 2) Additive risk transfer model - risks independent of background rates. In addition, a Mixture model is often considered where the multiplicative and additive transfer assumptions are given weighted contributions. We studied the influence of the survival probability on the risk of exposure induced cancer and circulatory disease morbidity and mortality in the Multiplicative transfer model and the Mixture model. Risks for never-smokers (NS) compared to the average U.S. population are estimated to be reduced between 30% and 60% dependent on model assumptions. Lung cancer is the major contributor to the reduction for NS, with additional contributions from circulatory diseases and cancers of the stomach, liver, bladder, oral cavity, esophagus, colon, a portion of the solid cancer remainder, and leukemia. Greater improvements in risk estimates for NS are possible, and would be dependent on improved understanding of risk transfer models, and elucidating the role of space radiation on the various stages of disease formation (e.g. initiation, promotion, and progression).

Methods
ESTIMATING RADIATION RISKS:
The cancer radiation risks for never-smokers (NS) were considered by Cucinotta et al. (2011) in both a Radiation Research article and a NASA publication. The cancer models considered here were transferred to the NASA 2010 Risk projection models which include model fits from BEIR VII, UNSCEAR 2006, and Preston (2007). We compare the multiplicative risk transfer models and the mixture model. We have also added coronary heart disease (CHD) and stroke radiation risks as estimated by Preston (2003).

ESTIMATING NEVER-SMOKER (NS) RATES:
US average rates and life tables are available online from the Centers for Disease Control’s website. Thun et al. provides a detailed review of lung cancer rates for NS with estimates (2008).

Table 1. Estimates of relative risks (RR) for never-smokers (NS) compared to the US average population for several cancers attributable to smoking, coronary heart disease (CHD), stroke, and chronic obstructive pulmonary disease (COPD). For males, current smokers, former smokers, and NS are estimated at 24%, 40%, and 36% of the population. For females, use 32%, 25%, and 47% of the population.

Table 2. Comparison of nRERD per Sv for males and females as a function of age at exposure for mixture model and multiplicative model for the US average population and never-smokers (NS) adjusted population.

Discussion
Astronaut Kaplan-Meier (KM) estimates for different demographics of US astronauts and payload specialists (PS) are shown in Figures 1A-C. There was data available for 339 astronauts with 44 deaths, and 23 PS with one death. 296 of the astronauts were male (M) and 40 were female (F). In Figure 1A, you can see that there is no significant differences between M, F, and PS, and all combined data. The low F and PS frequencies provide little power for statistical testing of differences. 18 of the deaths were work related and would not compare well with the average US population. For comparison these deaths were also censored at the time of the work related death. Figure 1B, shows how censoring the work related deaths changes the survival curve. Figure 1C and 1D compares the overall astronaut KM curve to the M and F US average and NS survival estimates. The work related deaths are included, the survival probability for lung cancer, smoking sensitive cancers, CHD, stroke, and COPD.

Figure 1. Comparison on estimated survivor functions conditional on surviving to age 30. Astronaut survival estimated using Kaplan-Meier estimates. US average and never-smokers (NS) estimates based on US 2005 life tables.

Figure 2. Comparison of nRERD per Sv for males and females as a function of age at exposure for mixture model and multiplicative model for the US average population and never-smokers (NS) adjusted population.

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