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REPLY

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Reply to comment by Rainer Facius et al. on "U.S. Government shutdown degrades aviation radiation monitoring during solar radiation storm"

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Abstract The premise of this comment perpetuates an unfortunate trend among some radiation researchers to minimize potential risks to human tissue from low-radiation sources. In fact, this discussion on the risk uncertainties of low-dose radiation further illustrates the need for more measurements and a program of active monitoring, especially when solar eruptive events can substantially elevate the radiation environment. This debate also highlights the context of a bigger problem; i.e., how do we as professionals act with due diligence to take the immense body of knowledge of space weather radiation effects on human tissue and distil it into ideas that regulatory agencies can use to maximize the safety of a population at risk. The focus of our article on radiation risks due to solar energetic particle events starts with our best assessment of risks and is based on the body of scientific knowledge while, at the same time, erring on the side of public safety. The uncertainty inherent in our assessment is accepted and described with this same philosophy in mind.

As our society's technology becomes increasingly dependent upon systems that have a susceptibility to space weather, we find that humans themselves also face potential risks from space weather. The radiation environment from galactic cosmic rays and solar energetic protons is one of the three space weather effects at commercial aviation altitudes and higher. Disrupted high-frequency communications and reduced Global Positioning System navigation accuracy are two other aviation technologies affected by space weather.

All the effects upon humans from an elevated radiation environment, which is found at and above commercial aviation altitudes, are still unknown, including the effects of low-radiation exposure. New effects continue to be found such as *Grajewski et al*. [2011], who identified previously unknown circadian cycle disruptions to pilots and crew from flying in an elevated radiation environment. Anecdotal evidence continues to point to possible increased cancer in pilots from malignant melanoma, astrocytoma, prostate cancer, and myeloid leukemia, [*Band et al*., 1996], so monitoring of in-flight radiation exposure and long-term follow-up of crew members is often recommended to further assess cancer risk in this occupational group.

The *ICRP Publication* 99 [2005] has noted that with "low-dose exposures it is extremely difficult to estimate the associated excess cancer risks by studying populations with exposures limited to the low-dose range. This is because, at low doses, the radiation-related excess risk, which is thought to be proportional to dose or perhaps somewhat less when compared with risks at higher doses, tends to be dwarfed by statistical and other variation in the background risk level in the absence of exposure. As a result, truly enormous sample sizes (e.g., millions) would theoretically be required to obtain a statistically stable estimate of radiation-related risk, and even then the estimate would be untrustworthy because we do not understand and therefore cannot control or adjust for, all of the sources of variation in baseline levels of risk." We agree with this and clearly identified the uncertainty in *Tobiska et al*. [2014] as we then proceeded to make a generalized, statistical evaluation of the conditions for the at-risk population.

The Facius, et al. comment basically boils down to an argument by those who believe that low-radiation doses are beneficial. A similar comment–reply exchange just occurred in the *Space Weather Journal* [*Socol et al*., 2014; *Mertens and Meier*, 2014]. This is a hotly debated topic called *radiation hormesis* or *adaptive response*, which is a hypothesis that says low-radiation doses in human cells can stimulate the activation of repair mechanisms that protect against disease. The body of scientific evidence [*NCRP Report 136*, 2001] has shown that adaptive response does not necessarily work for all human populations and that in cases where it does occur, the effect lasts for only a few hours. The NCRP Report "concludes that there is no conclusive

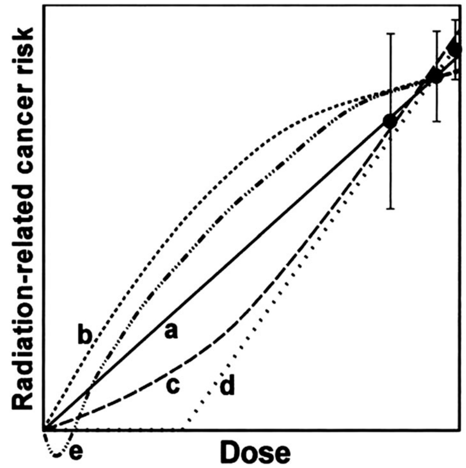

Figure 1. Schematic representation of different possible extrapolations of measured radiation risks down to very low doses, all of which could, in principle, be consistent with higher-dose epidemiological data. *Curve* (*a*), *linear no-threshold extrapolation*; curve (b), downwardly curving (decreasing slope); curve (c), upwardly curving (increasing slope); curve (d), threshold; and *curve* (*e*), *hormesis*, from *Brenner et al*. [2003].

evidence on which to reject the assumption of a linear no-threshold (LNT) dose–response relationship for many of the risks attributable to low-level ionizing radiation although additional data are needed." The U.S. National Research Council [*National Research Council*, 2006], the U.S. National Council on Radiation Protection and Measurements [*NCRP Report 136*, 2001], and the United Nations Scientific Committee on the Effects of Atomic Radiation [*United Nations Scientific Committee on the Effects of Atomic Radiation* (*UNSCEAR*), 2000] have all argued that there is no evidence for hormesis in humans; the NRC outright rejects hormesis as a possibility. All these scientific communities hold that the LNT model continues to be the model generally used by regulatory agencies for human radiation exposure. Figure 1 summarizes the various methodologies for extrapolating cancer risk versus radiation dose to low-dose levels. For our original paper we used curve (a). Thus, the *Facius et al*. [2014] disagreement over how to estimate low-dose risk ends up in a debate over which curve best fits high-dose and low-dose populations for cancer risk.

Are these curves perfect? Of course they are not. Without reinventing the wheel we chose to use the accepted LNT method, with all its uncertainty, because it is based upon the broad body of scientific and regulatory literature. *It is also the most conservative method that both provides an estimate for low-dose populations* and *errs on the side of public safety*.

For *Facius et al*. [2014] to criticize cancer risk estimates using a curve-fitting methodology they do not happen to like, calling it "numerology," is not only insincere but is misleading. It leads the flying public and crew away from understanding potential risks that can occur from moderate to large solar energetic particle events. Interestingly, the analogy of a frog slowly cooking in a pot of water that is gradually brought to a boil comes to mind—at an undefined threshold (depending upon the individual frog) it gets cooked. Who gets to decide for someone else when "it is too hot?" Do we not identify risk for the smaller events? Ignoring risk, at whatever level, is clearly unacceptable for most technologies. Risks must be directly identified and then studied, rather than dismissed arbitrarily and frivolously with name calling. We think the example of this debate about the risk uncertainties of low-dose radiation further illustrates a need for more measurements and a program of active monitoring.

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