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Supporting Information for

**Advances in atmospheric radiation measurements and modeling needed to improve air safety**

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Three paragraphs (Text S1 - S3) as the content for three separate sidebars.

**Additional Supporting Information (Files uploaded separately)**

**Introduction**

This is sidebar 1 for **tissue-relevant radiation**: Text S1.

An example of a severe tissue-relevant radiation environment occurred during the major SEP event on 23 February 1956 (only ground level measurements were available). For that event, Dyer et al. [2007] calculated a significant increase over background at high latitudes and at 12 km altitude with correspondingly higher dose rates for aircraft flight paths of several mSv hr⁻¹. The derived SI unit of ionizing radiation dose is the sievert (Sv). It incorporates the stochastic health risk of low levels of ionizing radiation on the human body, where radiation dose assessment is defined as the probability of cancer and genetic damage. On 23 February 1956 this radiation increase could have caused some aircrew members to exceed their currently recommended annual occupational flight limits in just one flight [Wilson, et al., 2002; Dyer et al., 2007]. It also could have caused upsets every 3 seconds in a Gbyte of a typical memory device [Dyer et al., 2003]. An extreme event such as the 1859 Carrington Event could be considerably worse than this event. Here we use the terms “extreme” or “severe” to indicate a NOAA S5 radiation storm, possibly comparable to the 1859 Carrington Event. We also note that the NOAA scales themselves are a poor indicator for the aviation radiation environment; the GOES fluxes are a good indicator of when a Solar Proton Event (SPE) is occurring but only...
small subsets of these have significant fluxes of protons with sufficient energy to affect the atmosphere, even at polar latitudes.

**Introduction**

This is sidebar 2 for **avionics-relevant radiation**:

**Text S2.**

A possible example of a severe neutron-induced avionics effect occurred on 07 October 2008 in Qantas Flight 72 Airbus A330-303 from Singapore to Perth, Western Australia. While the aircraft was in cruise at 37,000 ft, one of the aircraft’s three air data inertial reference units (ADIRUs) started outputting intermittent, incorrect values (spikes) on flight parameters to other aircraft systems. Two minutes later, in response to spikes in angle of attack (AOA) data, the aircraft’s flight control primary computers (FCPCs) commanded the aircraft to pitch down. At least 110 of the 303 passengers and 9 of 12 aircrew members were injured; 12 were serious injuries and another 39 required hospital medical treatment. The potential triggering event that was not ruled out was a single event effect (SEE) resulting from a high-energy atmospheric neutron interacting with one of the integrated circuits (ICs) within the CPU module. While there was insufficient evidence to determine that a SEE was the conclusive cause, the investigation identified SEE as an ongoing, probabilistically relevant risk for airborne equipment. All other known causes were eliminated. The aircraft manufacturer subsequently redesigned the AOA algorithm to prevent the same type of accident from occurring again [ATSB Transport Safety Report, 2011]. We note that the GOES >10 MeV proton fluence was nominal on this date, i.e., there were no solar flare events.

**Introduction**

This is sidebar 3 for **action needed at all levels**:

**Text S3.**

There is great value in stakeholders’ efforts to mitigate potential exposure risks to humans and avionics from events that affect the aviation radiation environment. Further efforts by stakeholders leading to near-term action can:

- expand international scientific research in the aviation radiation environment;
- develop reliable, new measurement systems that can provide calibrated real-time dose equivalence data for a highly mixed and changeable radiation field;
- obtain in-flight measurements during solar particle events in order to calibrate instruments and validate models;
- test semiconductor devices at a wide energy neutron source as part of certifying their use in avionics;
- continue and expand ground level neutron monitor measurements to record GLEs as a subset of SPEs;
- create new modeling systems that can assimilate real-time radiation data;
- discover and validate new forecasting capabilities;
- combine data and modeling for improved monitoring in an operational context;
- provide current condition information to decision makers (pilots and dispatchers);
- train decision makers on the information available;
• educate airline personnel, managers, dispatchers, and pilots on the exposures, measurements, risks, as well as mitigation techniques available;
• provide feedback to the scientific community on the adequacy of the information provided to the decision maker; and
• provide the public with scientific-based, but easily understood, information on the aviation radiation environment.

References

