SiGLE: computing radiation doses due to GLEs onboard aircrafts within the SIEVERT system

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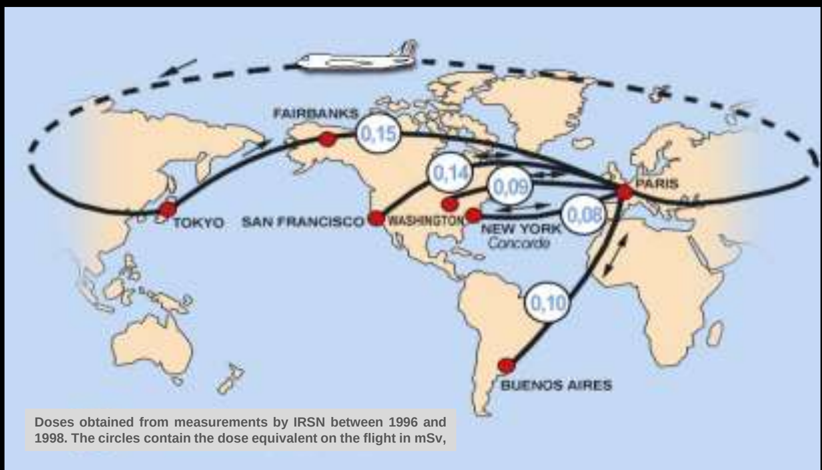
In 2000, the European Commission directive set limits to the exposure of aircraft crew to cosmic radiation. The effective dose should not be higher than 100 mSv over 5 years with a maximum of 50 mSv for a given year. The radiation doses onboard aircraft are due to two sources: Galactic Cosmic Rays (GCR) and Solar Proton Events (SPE). The doses are the result of the numerous secondary particles created in the atmosphere by high energy primary particles. The galactic component is permanent but modulated by the solar activity in the course of the 11-year solar cycle. The SPE, when detected at ground level by neutron monitors (GLE), may enhance significantly the doses received onboard aircraft. A specific semi-empirical model named SiGLE was developed (Lantos & Fuller, 2003) to take into account these events. It benefits since a few years of the Neutron Monitor DataBase (NMDB) which collects data from numerous Neutron Monitors all over the world. Within the European Radiation Dosimetry Group (EURADOS), doses computed by several models were compared and assessed for the GCR. The same comparison is ongoing for SPEs models and a measurement campaign initiated by IRSN (Institute for Radiation Protection and Nuclear Safety) should give important clues to validate the different approaches in the near future. Using EPCARD and SiGLE, the computerized system for flight assessment of exposure to cosmic radiation in air transport, or "SIEVERT" (Bottollier-Depois, 2003), was proposed to airline companies to assist them in the application of this legal requirement. This professional service is also accessible to any passenger who whish to estimate the dose received during a given flight (www.sievert-system.org).

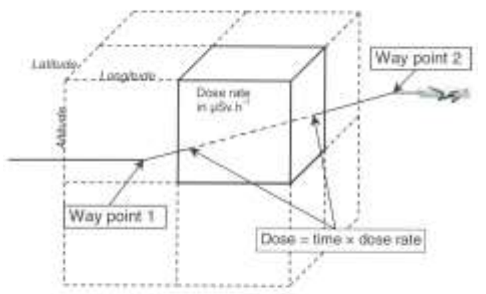


Doses obtained from measurements by IRSN between 1996 and 1998. The circles contain the dose equivalent on the flight in mSv,

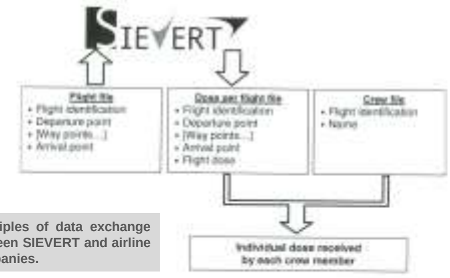
The SIEVERT principle

Airspace is divided into cells. Each one is 1000 feet in altitude, 10° in longitude and 2° in latitude. Altogether they form a map of 265,000 cells; each cell is assigned an effective dose rate value using EPCARD model (Schraube, 1999). The time spent by the plane in each cell and the corresponding dose are calculated in order to compute the dose received during the whole flight.

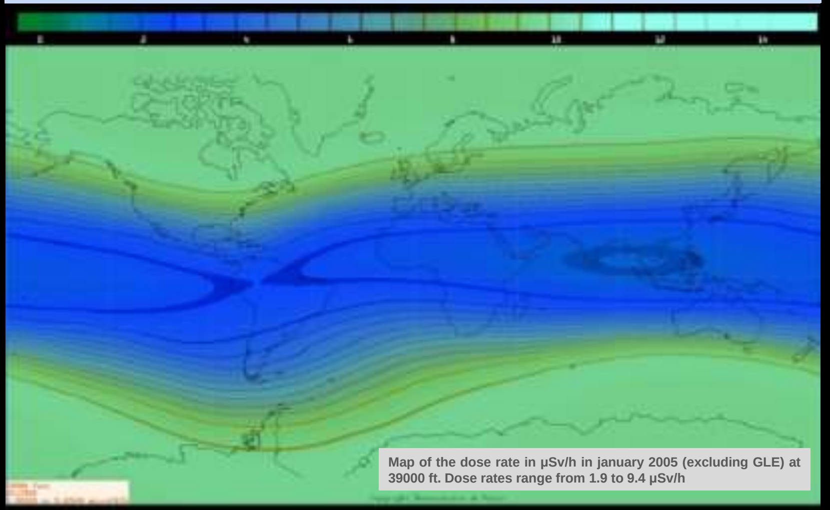
The IRSN updates the map of the dose rates every month by taking solar activity into account. A map of the hourly dose at a typical subsonic altitude is given as an example for January 2005. In the case of a GLE, a specific map is created (see below). In addition, regular radiation measurements from dosimeters installed on the ground and on aircraft are used to confirm and, if necessary, to correct the model values. IRSN started a new campaign of measurements in march 2013, with the partnership of Air France (see presentation by F. Trompier).



Dose calculation principle with SIEVERT



Principles of data exchange between SIEVERT and airline companies.

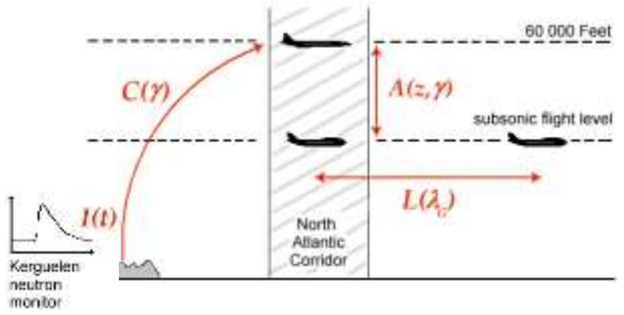


Map of the dose rate in µSv/h in january 2005 (excluding GLE) at 39000 ft. Dose rates range from 1.9 to 9.4 µSv/h

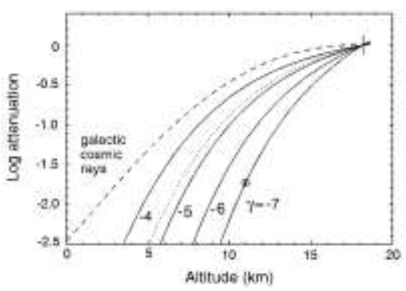
The SiGLE principle

The semi-empirical model SiGLE combines few available measurements obtained on board Concorde during GLEs in 1989 and 2000 and on board a subsonic flight during a GLE in 2001, with calculations based on particle transport codes for GLE 42 on 29 September 1989, to compute an estimate of the dose **D**(t) received during GLEs .

$$D(t) = A(z,\gamma) \times L(\lambda_G) \times C(\gamma) \times I(t)$$



From the Air France and British Airways measurements, a linear relationship **C**(γ) between ground based neutron monitor GLE time profiles and dose rates at 60000ft in altitude is derived for different particle rigidity spectral exponents (noted γ). The rigidity spectrum is given by the NMDB consortium computations (see below).

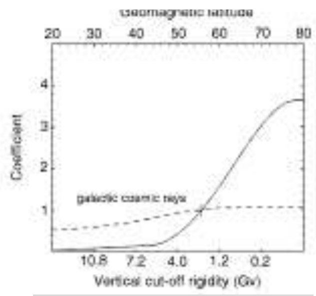


Logarithm of the attenuation of dose equivalent rate in function of altitude for different values of the rigidity spectrum exponent γ. Attenuation for galactic cosmic rays is indicated with dashed line and attenuation for GLEs with average rigidity spectrum exponent γ = - 4.7 is indicated with a dotted line.

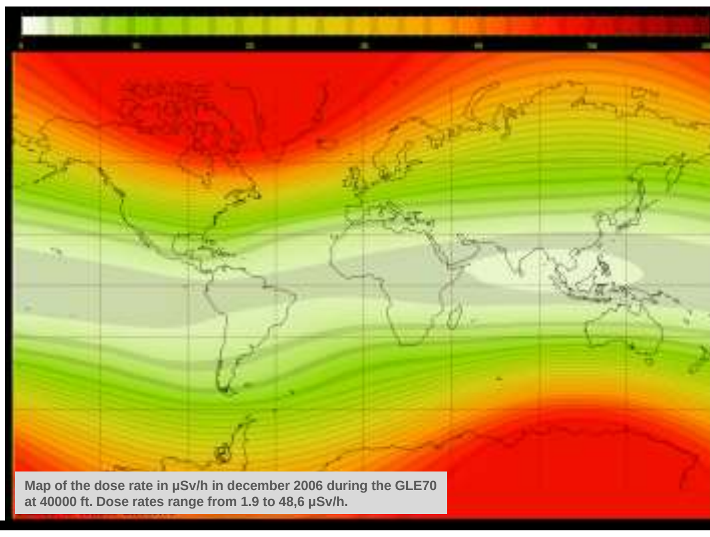
The measurement on board a Czech Airlines flight from Prague-to New York (Spurný & Dachev, 2001), during the GLE numbered 60, on 15 April 2001, as well as plots based on theoretical calculations by O'Brien et al. (1998), are used to derive the attenuation factor **A**(z,γ) between dose rate at 60000ft and dose rate at the aeroplane altitude, noted z, in relative scale.

The **L**(λ_G) function gives the variation of the dose rate with the geomagnetic latitude at subsonic altitudes in relative scale. It is estimated using results of dose rate calculation during GLE 42 (O'Brien & Sauer, 2000) at the Greenwich meridian.

The reference monitor for the model is Kerguelen Islands, in the South Indian Ocean. It is located at Port-aux-Français (λ_G = 57.5°S and vertical cut-off rigidity of 1.1 GV) . It is operated by the French Institute for Polar Research (IPEV).



Dose equivalent rate coefficient L in function of the geomagnetic latitude for subsonic altitude 35000ft. The reference latitude corresponds to North Atlantic routes. Lower axis gives corresponding vertical cut-off rigidity for northern hemisphere and European sector .



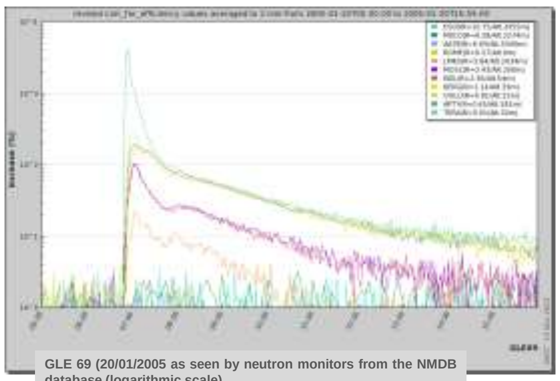
Map of the dose rate in µSv/h in december 2006 during the GLE70 at 40000 ft. Dose rates range from 1.9 to 48,6 µSv/h.

When the N/S anisotropy of the event is significant, like it was during the strong GLE 69 of the 20/01/2005, we can use other monitors from the NMDB database to take the anisotropy into account. A typical flight from San-Francisco to Paris received 175 µSv during this GLE with 102 µSv due to solar particules

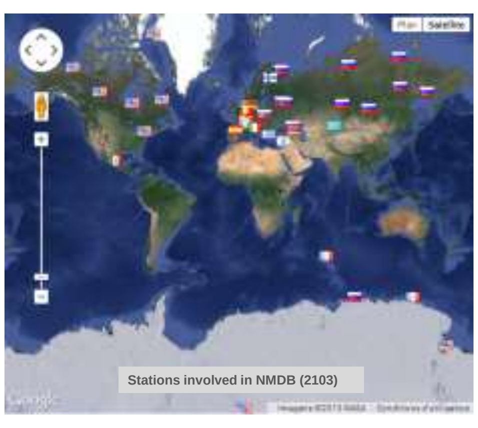
The NMDB database

NMDB is a project which involved teams from 12 different countries, funded in 2008-09 by the European Union's 7th Framework Programme. Many neutron monitors across the world have pool their data to make them available in real time and have easy-to-use data products to scientists and others (see presentation by R. Butikofer). NMDB now (2013) counts about 30 monitors in real time (lag lower than 10 min) and more than 40 monitors in total. New providers are still expected in the future years.

Among all the applications which were build based on NMDB, two groups developed tools which are of primary interest for radiation dosimetry aboard aircrafts: real time GLE parameters calculations (NKUA and IZMIRAN). Those tools use the real time NMDB measurements to estimate the exponent of SCR spectrum, together with anisotropy source coordinates and amplitude. This gives the possibility to compute a first estimation of radiation doses in a fast manner.

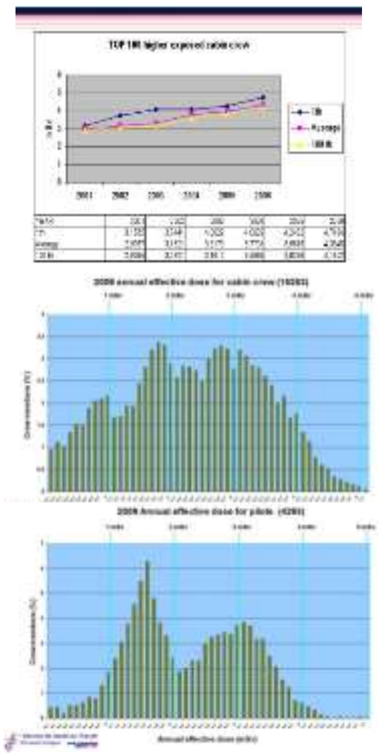


GLE 69 (20/01/2005 as seen by neutron monitors from the NMDB database (logarithmic scale)



Stations involved in NMDB (2103)

EURADOS is a network of more than 50 European institutions involved in radiation dosimetry. Eurados is the ideal structure to facilitate the intercomparison of codes developed in different countries across Europe and even in other countries. Many codes computing galactic cosmic ray effects aboard aircrafts together with codes more specifically dedicated to Solar Particles effects are involved in this attempt to assess doses and resolve possible discrepancies.



End user feedback: Air France

Air France is the main professional user of the SIEVERT system (about 50000 flights each month). To obtain the monthly and annual exposures of its crewmembers A.F. adds the doses received during each flight carried out to the personnal dose files. When a crewmember comes to the occupational health service for his annual exam, the physician tells him the result of his exposure, as the one shown on the left. On this example we can notice that the "eruption" of December 2006 has been taken into account.

Considering the data collected over 6 years (2001-2006), A.F. observes that the top 100 higher exposed flight deck crew are included between 3,8 and 4,9 mSv per year and cabin crew between 4,2 to 4,8. More recent data (2009) show that the pilots rarely exceed a dose of 4 mSv/year while it is more frequent for cabin crew members (but still below 5 mSv). There is a trend to ascent over the past years. A part of this increase could be due to normal solar cycle's variations, mainly because of the long lasting solar minima, but the main part is probably due to a better productivity (about 750 boarding hours per year). Moreover, more and more flights are operated from France to Japan and northern America which means higher latitudes and dose rates. A.F. considers that with an action point at 4 mSv, the working schedule could be modified in order to avoid doses upon 6 mSv/year, which is the limit between class B and class A radiation workers (more restrictive monitoring rules).