Are terrestrial gamma-ray flashes a danger or not for passengers and crew members of commercial flights?

Joana Mingacho[1,2], R. M. Curado da Silva[1,2], M. Moita[1,2], J. M. Maia[1,3]

[1] *LIP-Laboratório de Instrumentação e Física Experimental de Partículas, Coimbra, Portugal*
[2] *Department of Physics, University of Coimbra, Coimbra, Portugal*
[3] *Department of Physics, University of Beira Interior, Covilhã, Portugal*

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

1290 UNIVERSIDADE D COIMBRA

FACULDADE CIÊNCIAS Departamento de Física

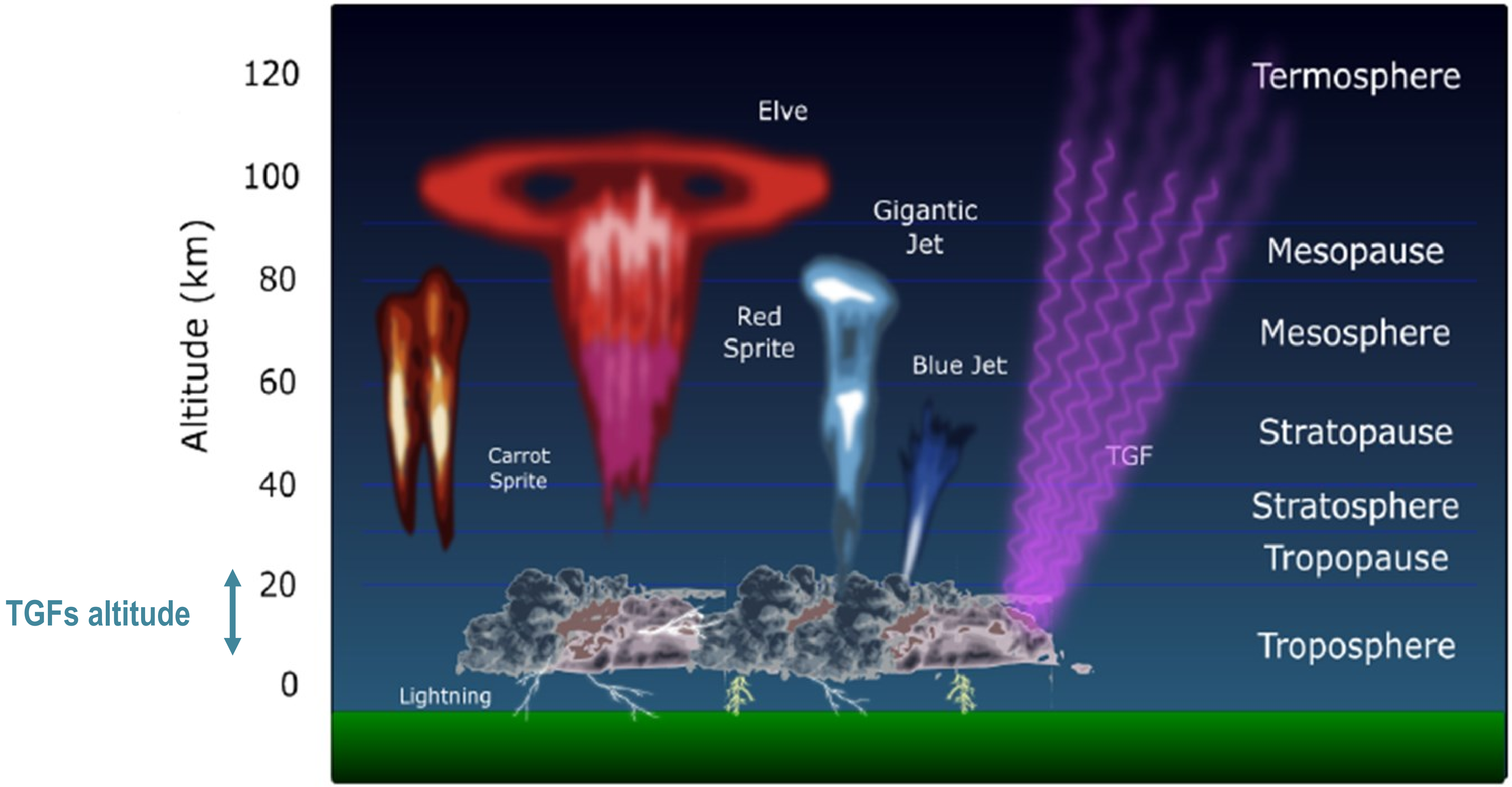


Figure 1: Terrestrial events, by Alessandro Ursi, eASTROGAM Workshop - March 1st 2017, Padova.

Terrestrial Gamma-Ray Flashes

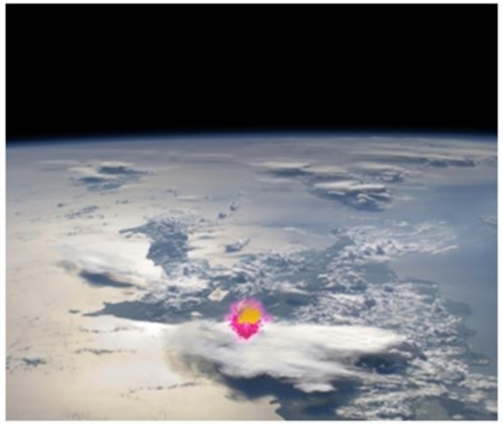


Figure 2: Initial upward-moving avalanche.

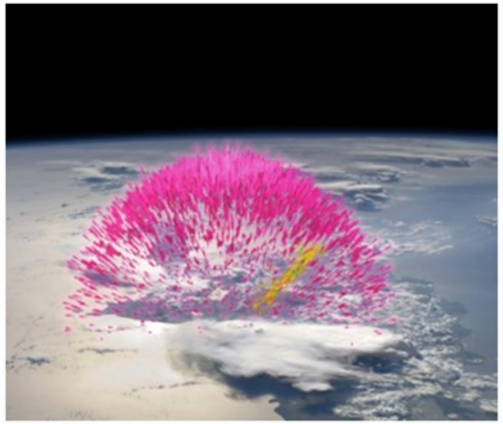


Figure 3: TGF emission.

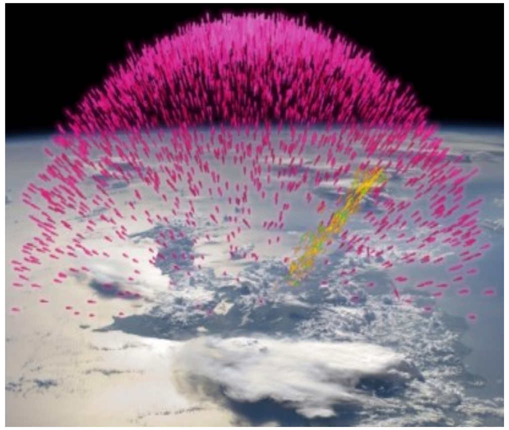


Figure 4: 0.2 ms duration TGF.

These images are based on a simulation of TGF by Joseph Dwyer at the Florida Institute of Technology. It is a TGF that started at an altitude of 15 km.

Credit: NASA/Goddard Space Flight Center/J. Dwyer, Florida Inst. of Technology

Terrestrial Gamma-Ray Flashes

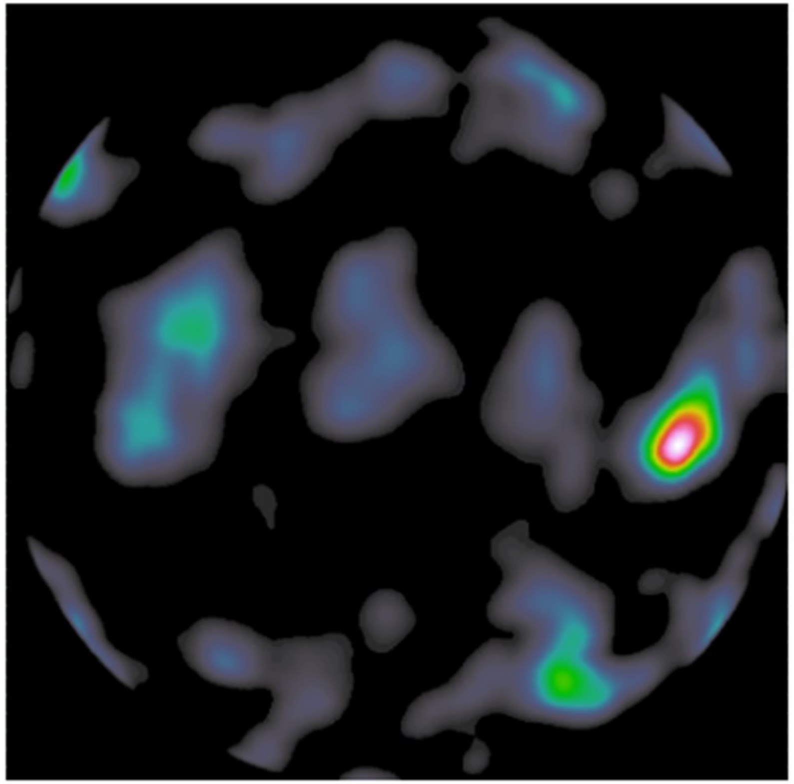


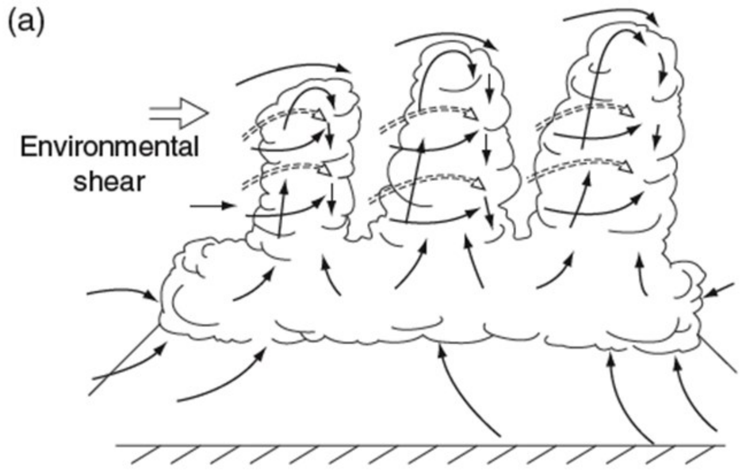
Figure 5: Global image of terrestrial gamma-ray flashes by ESA.

Figure 6: Instrument ASIM by ESA.

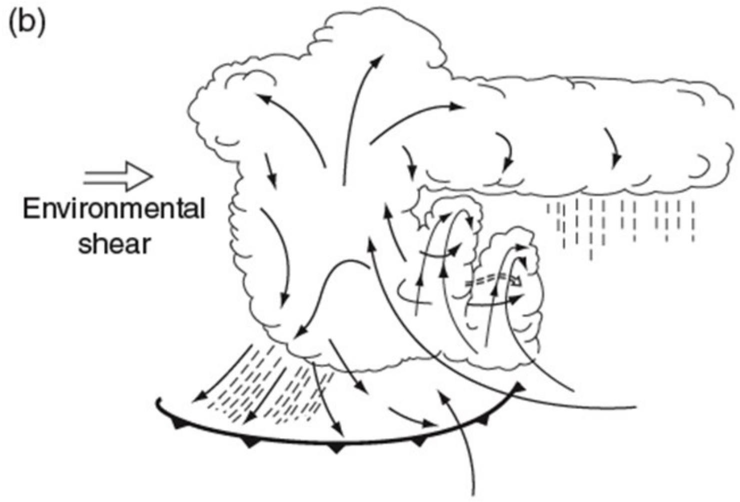
Space instruments:

- BATSE
- RHESSI
- GBM – Fermi
- AGILE

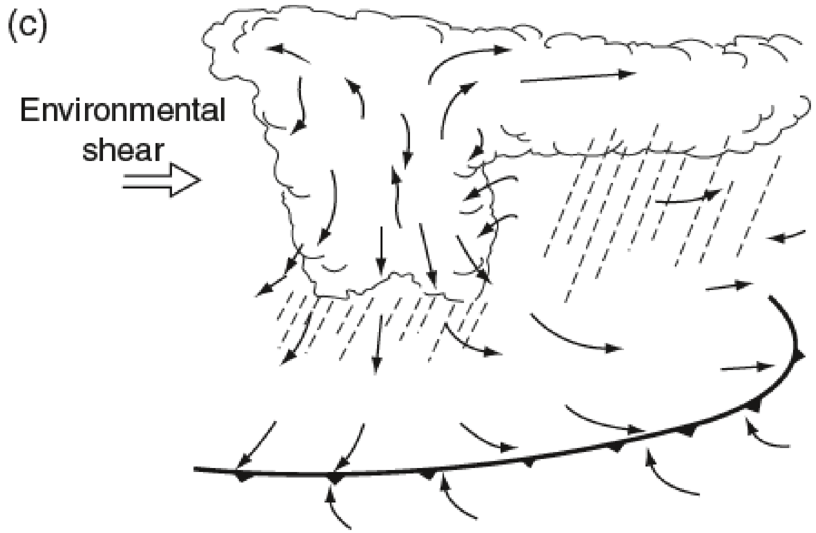
Cumulonimbus clouds



a) The cumulus stage



b) The mature stage



c) The dissipation stage

Cumulonimbus clouds

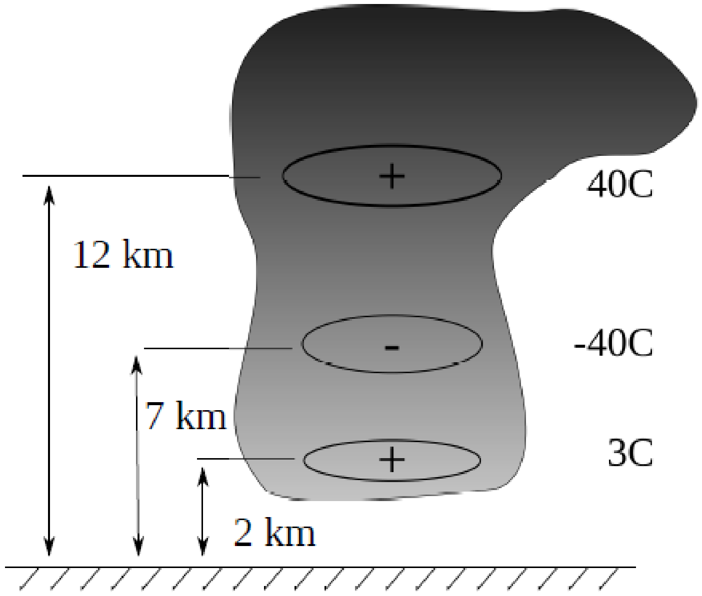


Figure 7: Tripole structure of a cumulonimbus cloud.

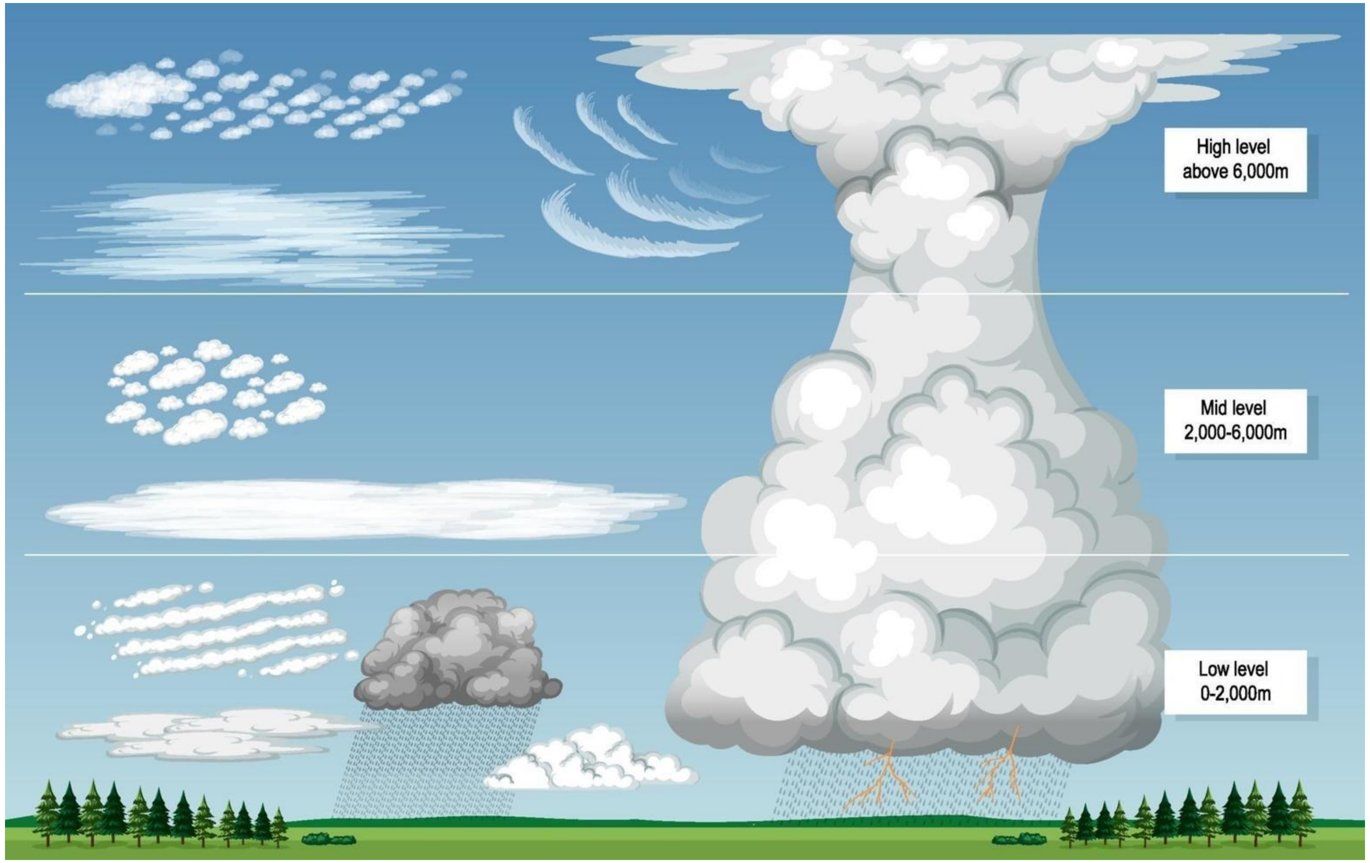


Figure 8: Cloud set.

Lightning Activity

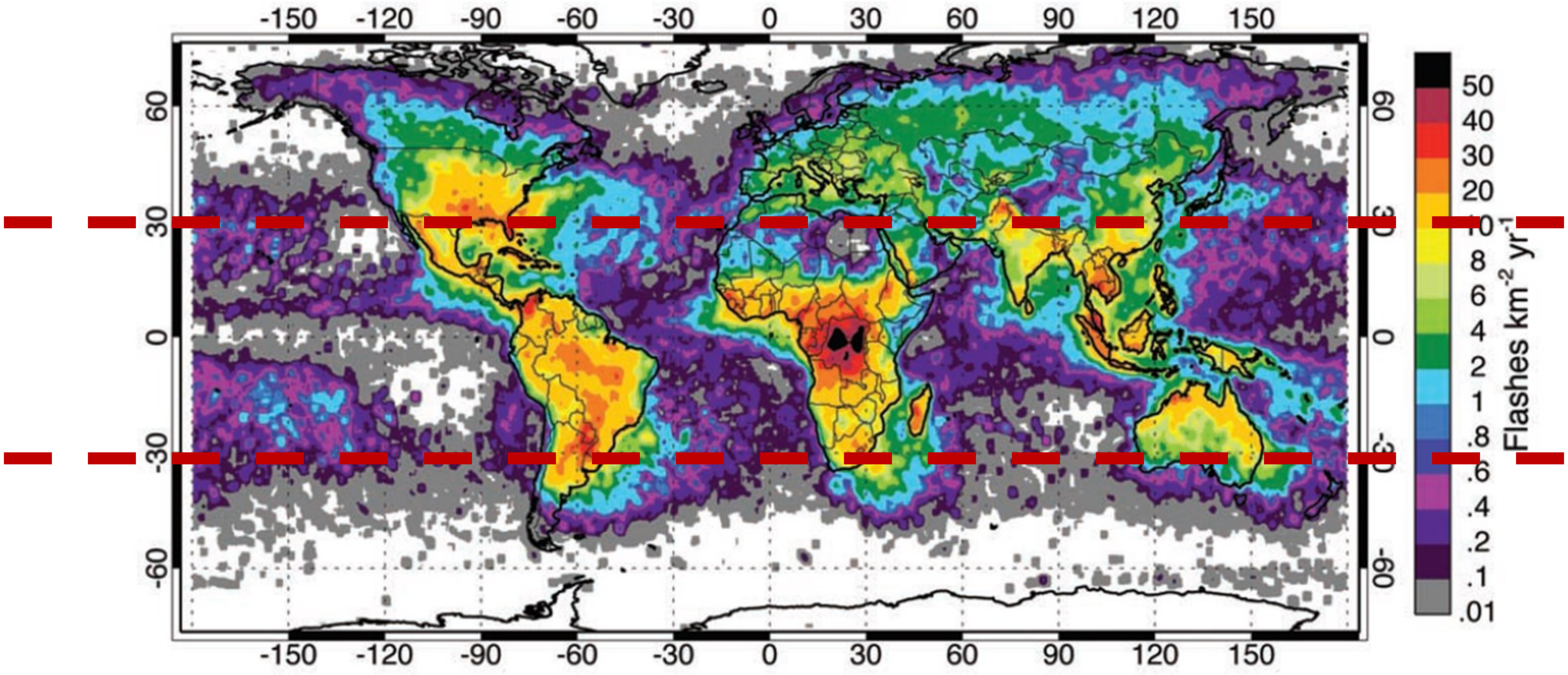


Figure 9: The annualized distribution of total lightning activity (in units of fl/km^{-2} yr^{-1}).

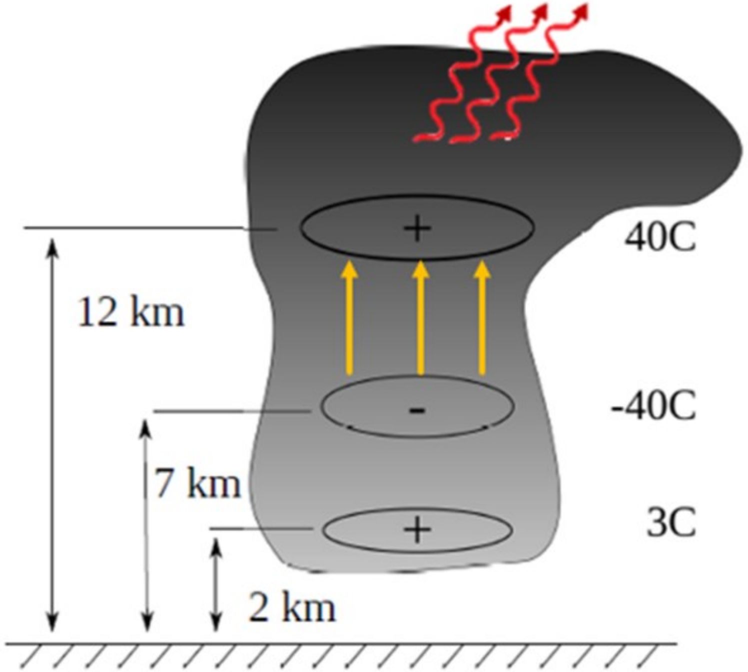


Figure 10: Tripole structure of a cumulonimbus cloud with a TGF emission.

Terrestrial Gamma-ray Flashes emission; video by NASA.

Production process

Commercial aircraft

Figure 11: Boeing 787 Dreamliner; 62.8 m long and 17 m high.

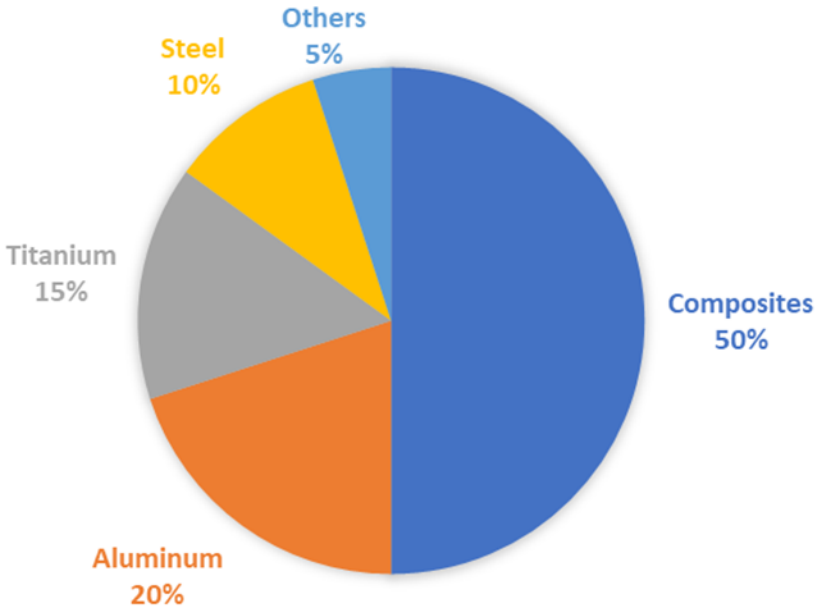


Figure 12: Boeing 787 Dreamliner components.

Interactions with the aircraft structure

$$\gamma + {}^{27}Al \longrightarrow {}^{27}Al^* \longrightarrow {}^{26}Al + n$$

$$\gamma + {}^{12}C \longrightarrow {}^{12}C^* \longrightarrow {}^{11}C + n$$

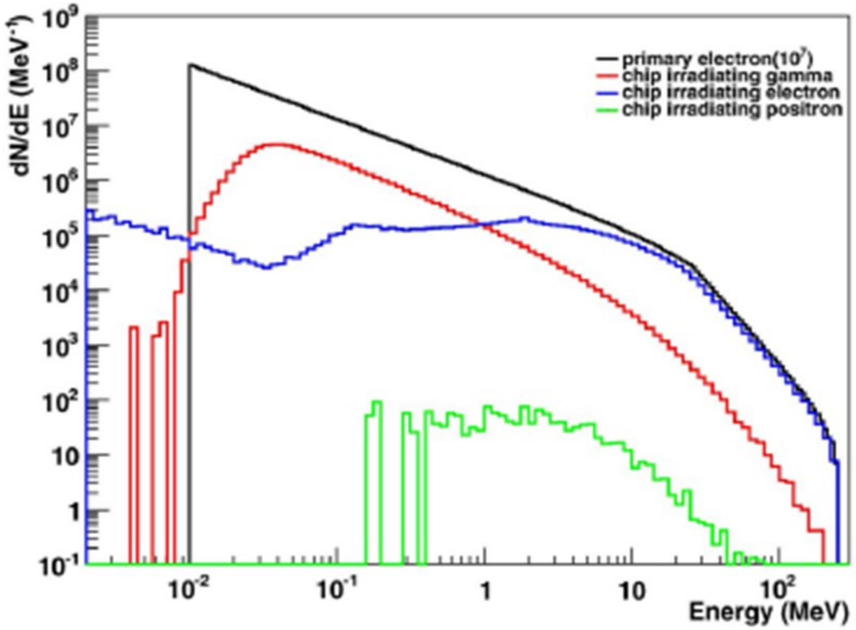


Figure 13: An example of a possible equipment irradiation for an aircraft exposed to a flux of incoming electrons.

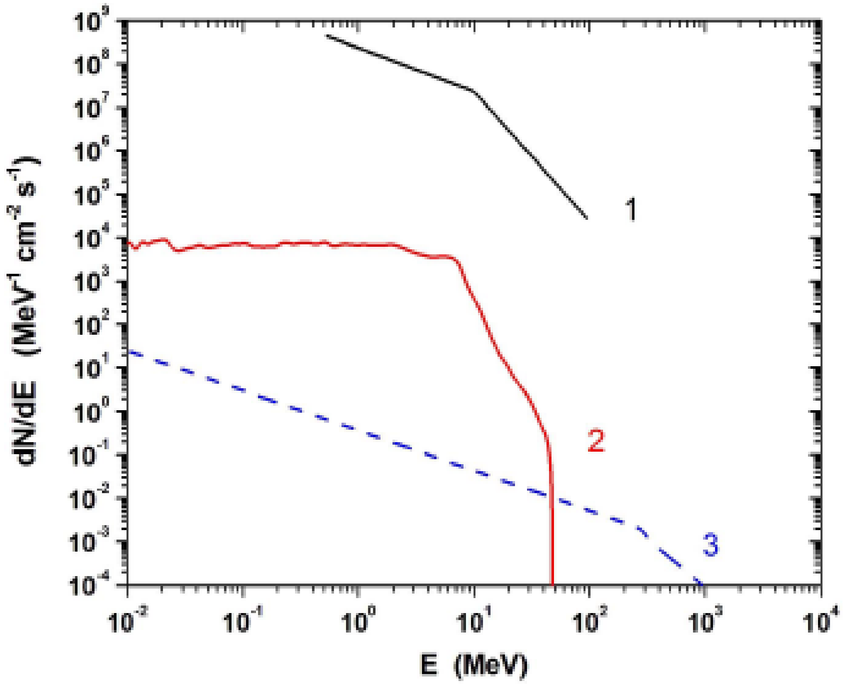


Figure 14: An example of TGF irradiation on aircraft, producing photo-production of secondary neutrons.

Questionnaire to the aircraft pilot and to the commercial aircraft mechanics

1. Do aircraft routes change often? If so, how often?

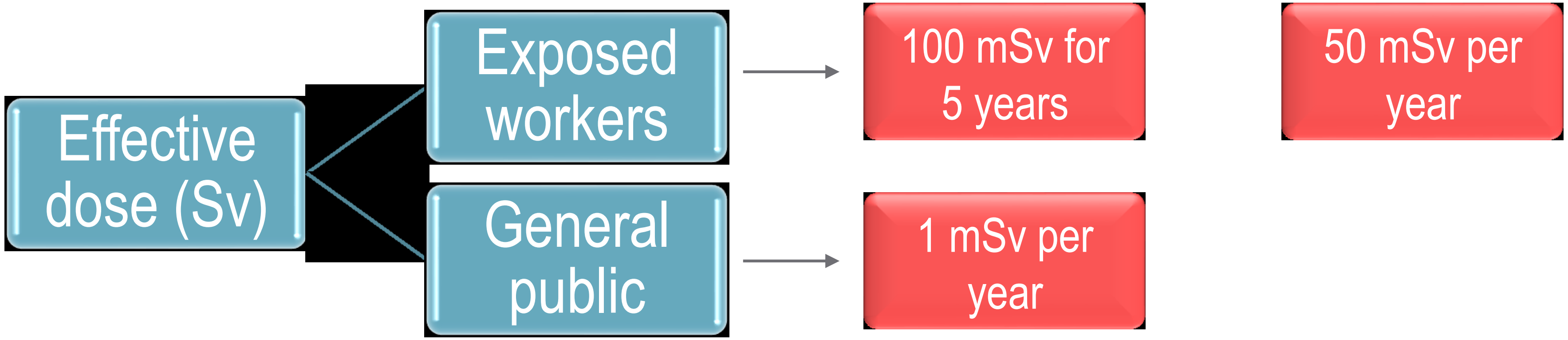
2. When or under what conditions can an aircraft cross a storm cloud?

3. How can radiation affect aircraft electronics during the flight?

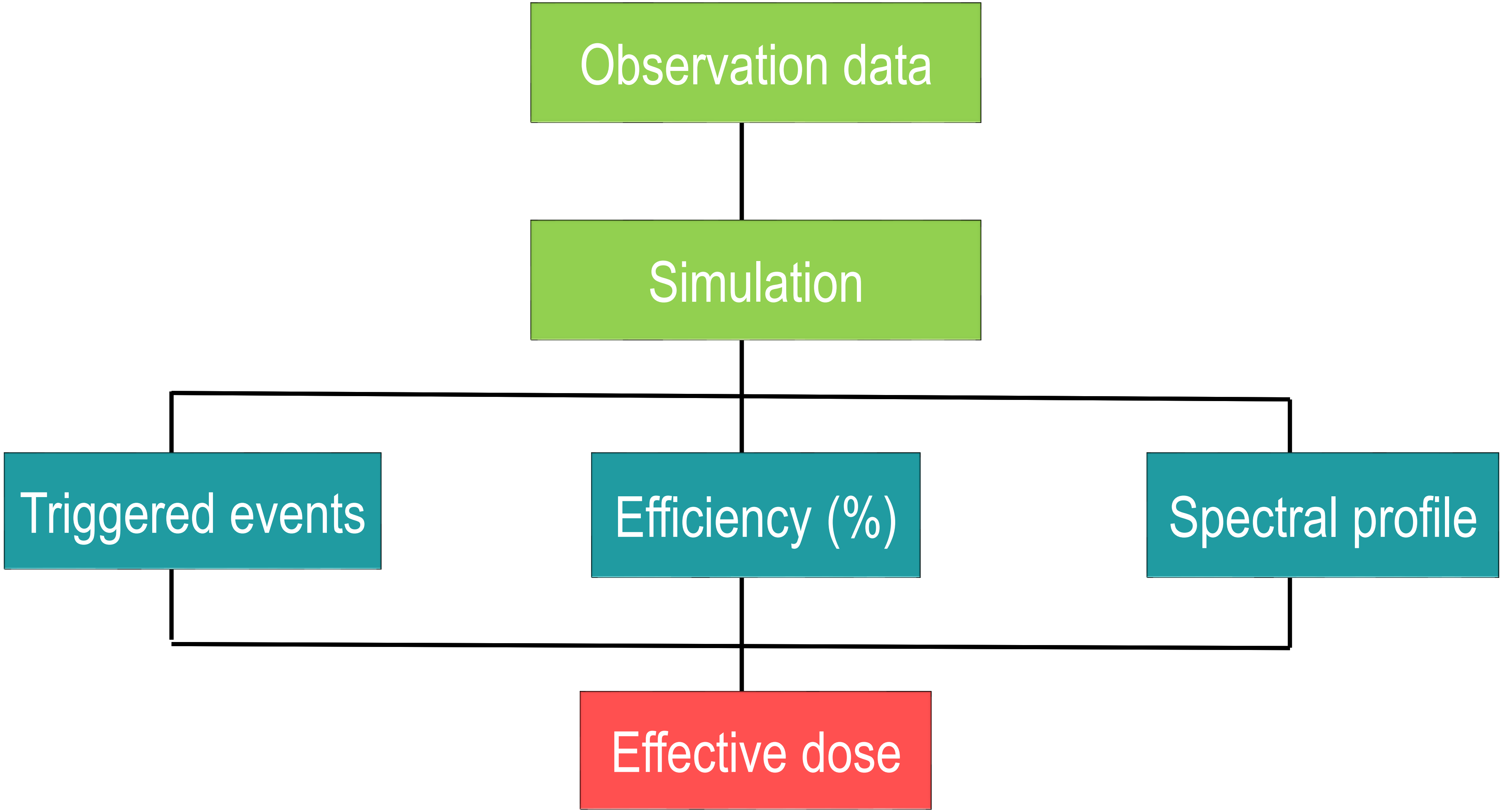
4. After a flight, are measurements made of the radiation that was absorbed by the aircraft? Or is there any mechanism that does something similar or that controls the absorbed radiation?

Radiation Doses

$$D = \frac{d\bar{\varepsilon}}{dm}\ [Gy] \qquad H_T = \sum_R w_R D_{T,R}\ \text{Sievert}\ [Sv] \qquad E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R}\ [Sv]$$



Methodology



Methodology

Altitude, km	Column Density, g/cm^2
10	270
15	129
20	62
30	14
40	3.2
50	0.74
60	0.17

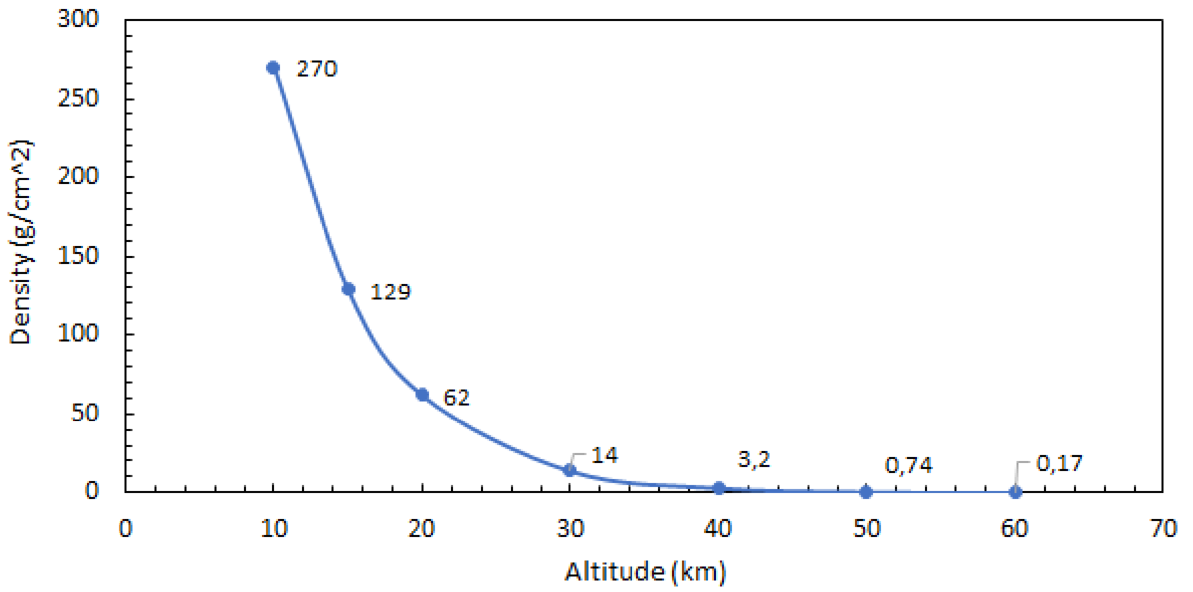
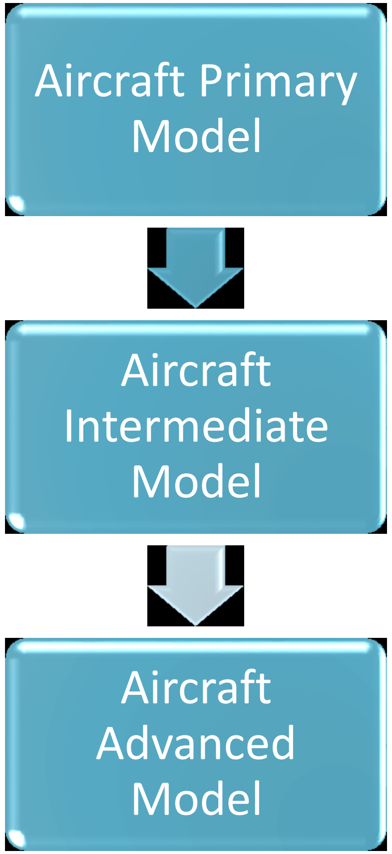


Figure 15: Atmospheric density for different altitudes.



Aircraft Primary Model Simulation Set

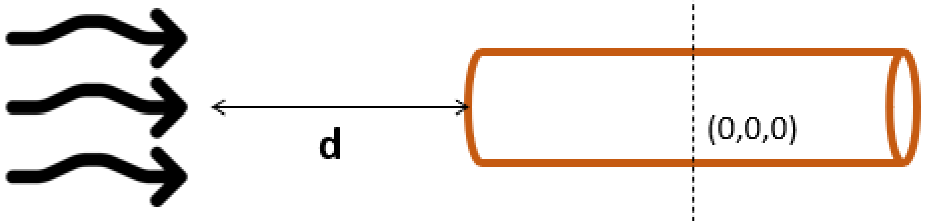


Figure 16: Diagram for a beam hitting the aircraft primary model.

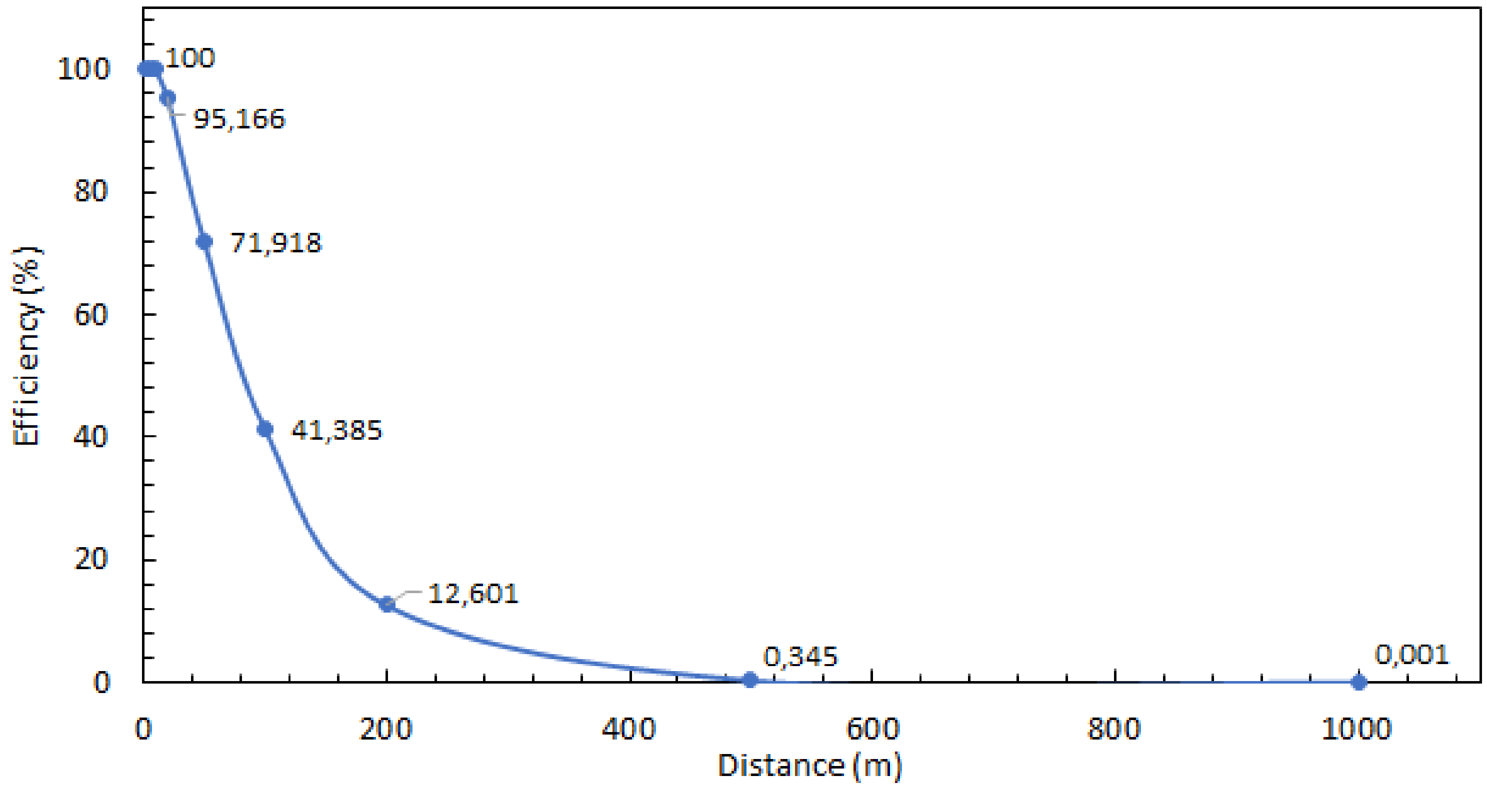


Figure 17: Efficiency (%) for the aircraft primary model as a function of source distance (m), for a 300 keV beam in air, at 1 atm.

Aircraft Primary Model at 10 km altitude

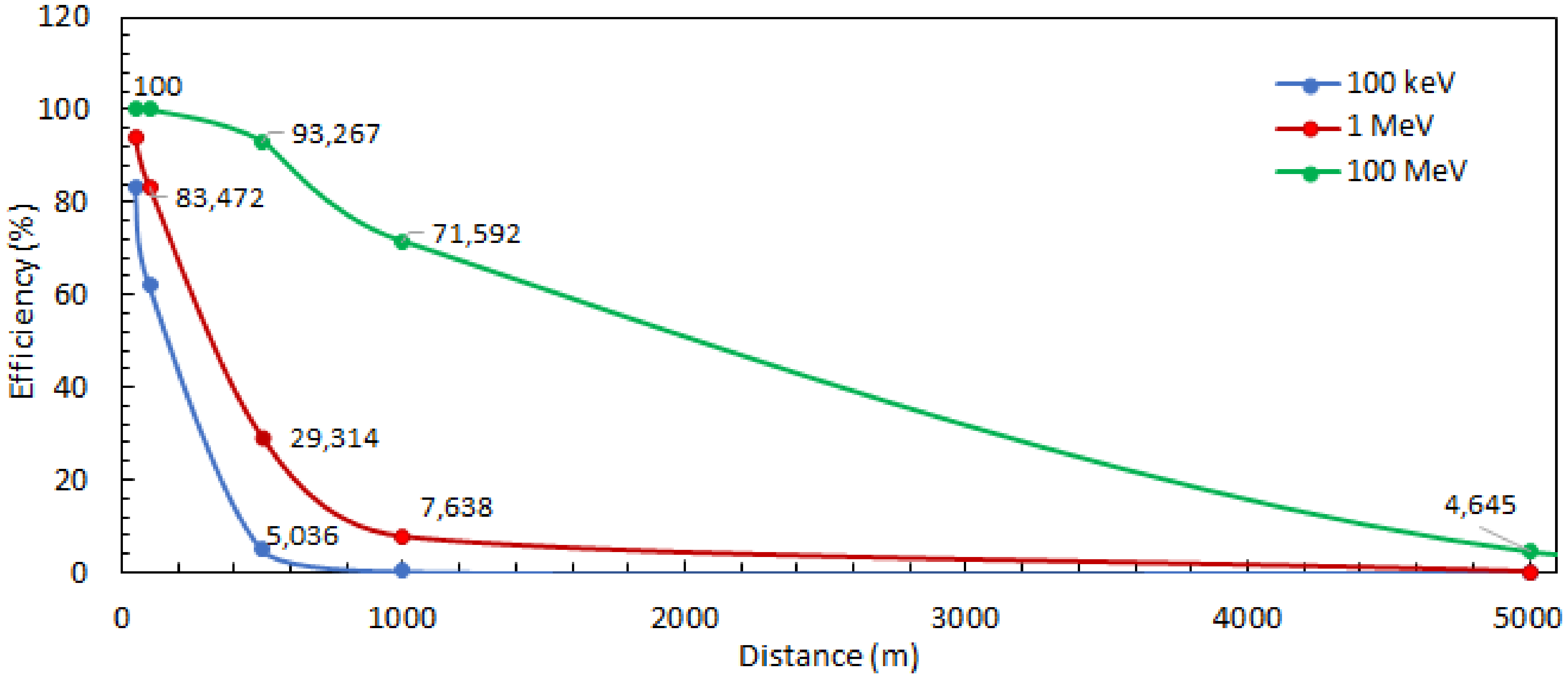


Figure 18: Efficiency (%) for the aircraft primary model as a function of source distance (m), for a 100 keV, 1 MeV and 100 MeV beam at 10 km altitude.

Cone Beam and Real Flux

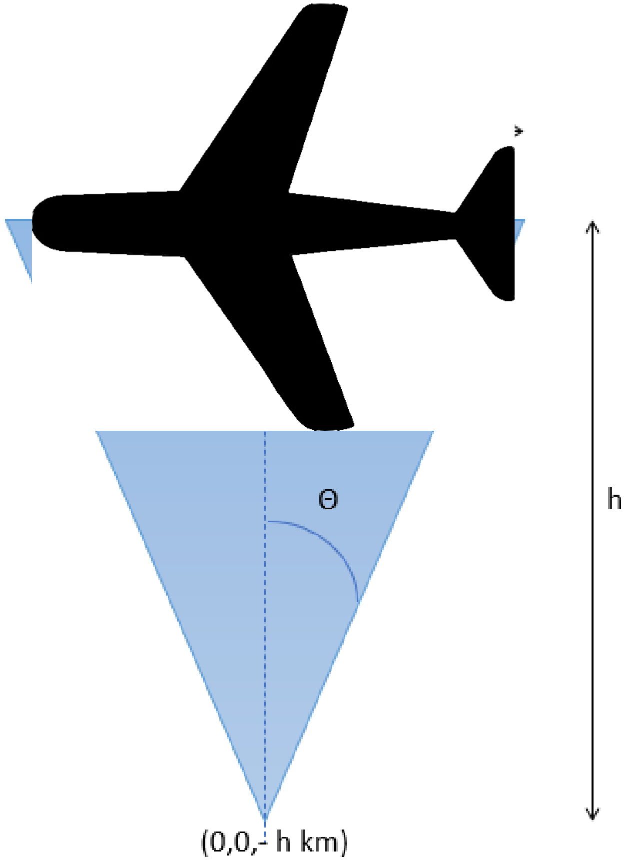


Figure 19: Geometry scheme used in the simulations for photon emission.

h values:
5 km
2.5 km
0.5 km

$$\frac{dN}{dn} = A_0 n^{-\lambda}$$

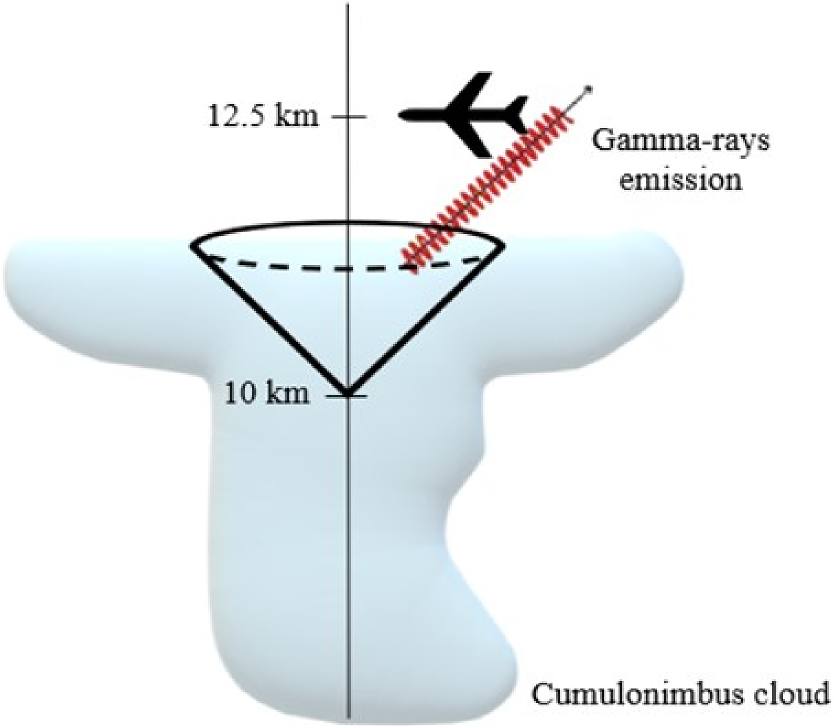


Figure 20: Schematics of the simulation geometry to estimate the radiation effective dose in a human model inside a commercial aircraft.

Aircraft Intermediate Model: With Aluminum and Air

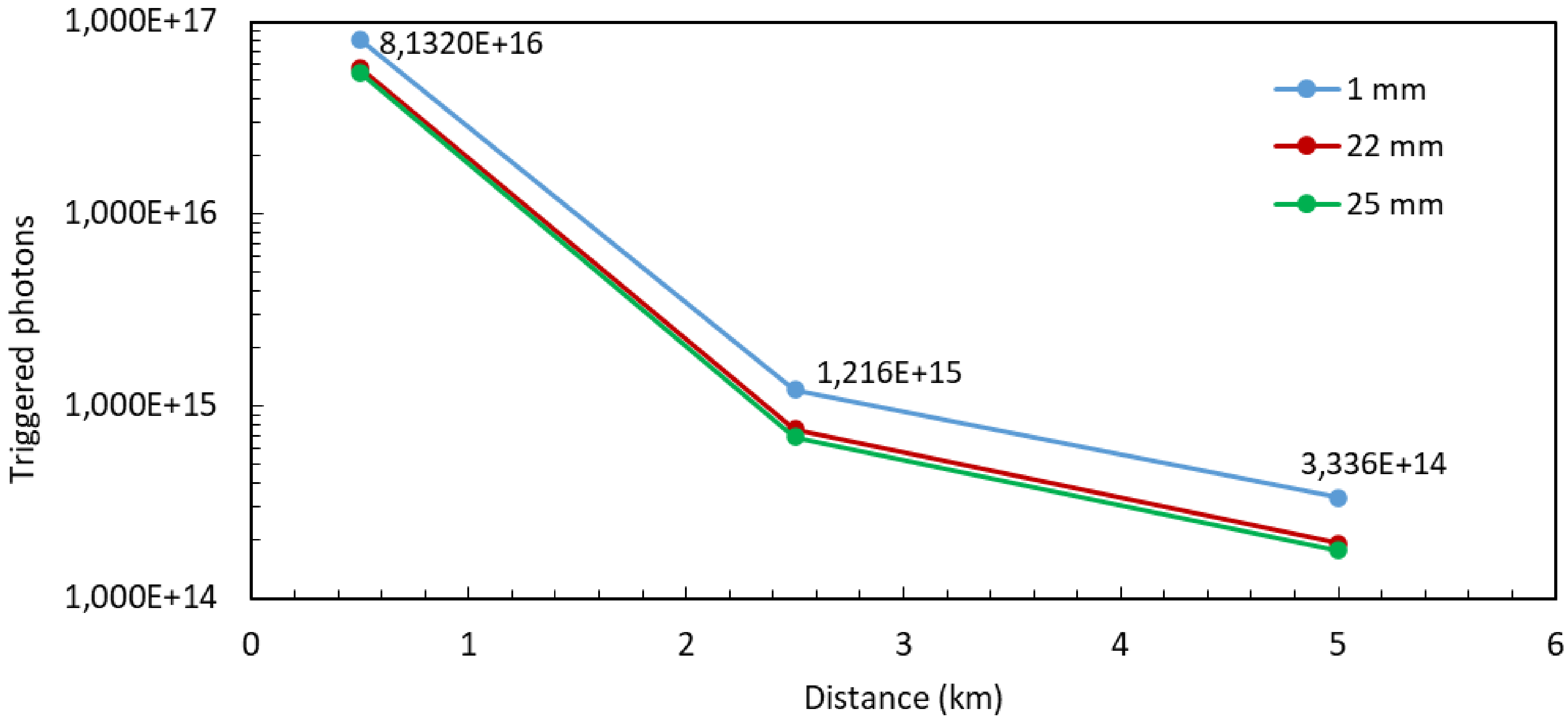


Figure 21: Triggered photons for a linear extrapolation to 100 μs considering a cone beam incident on the aircraft intermediate model, for three different fuselages thicknesses.

Aircraft Advanced Model: Phantom

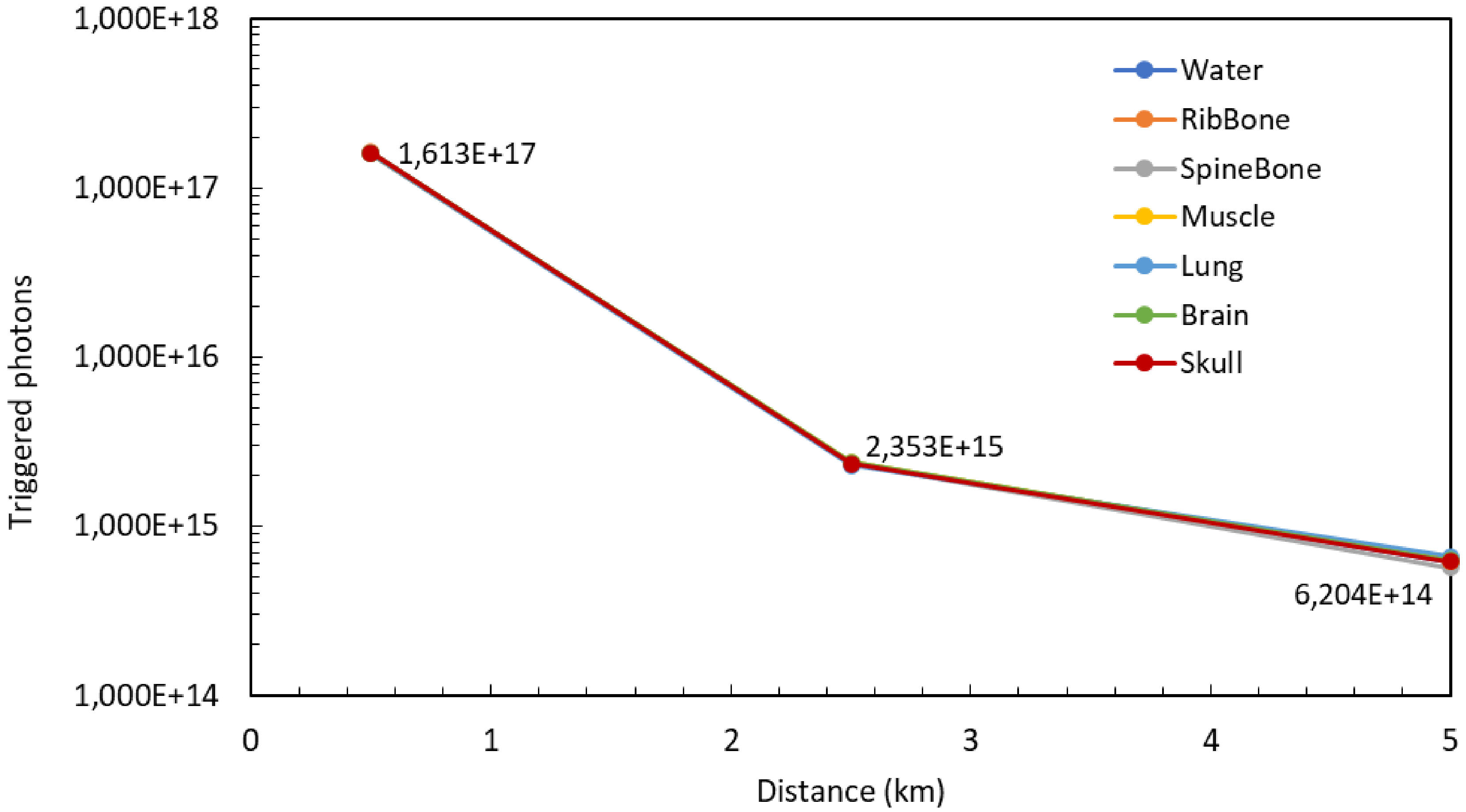


Figure 22: Triggered photons for a linear extrapolation to 100 μs, considering a cone beam incident on the aircraft advanced model, for each phantom component.

Human Model

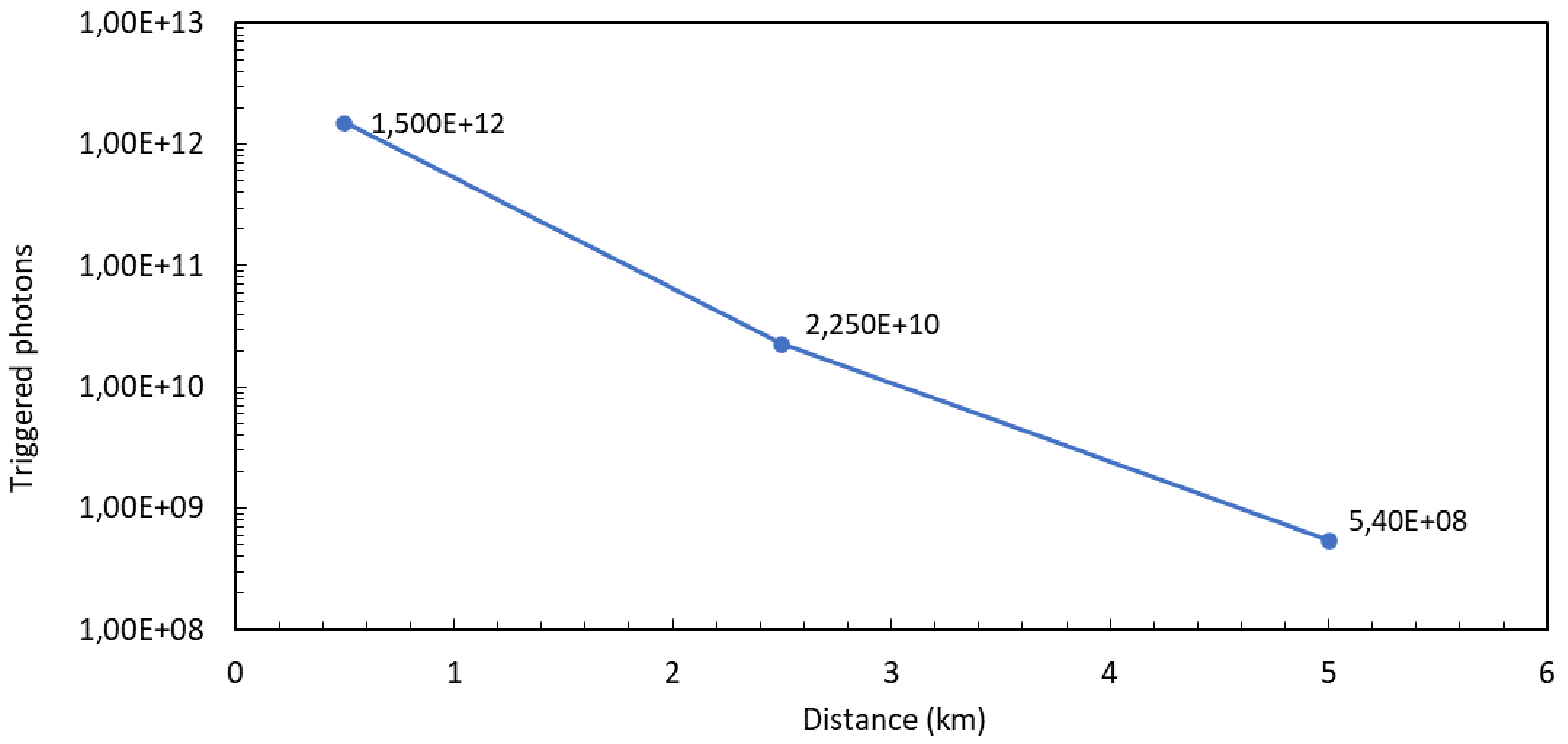


Figure 24: Triggered photons for a linear extrapolation to 100 μs considering a cone beam incident on human model, inside the aircraft advanced model.

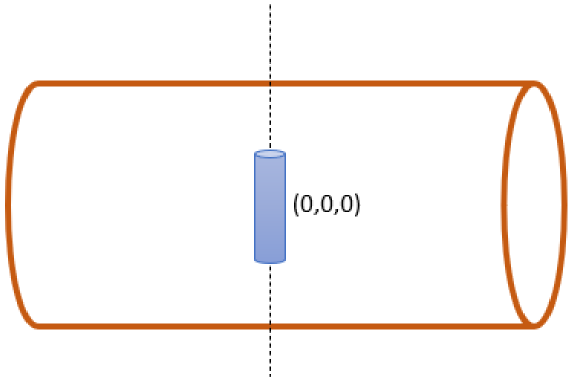


Figure 23: Diagram for the approximate human model, with cylindrical geometry, inside the aircraft advanced model.

Absorbed dose for a human inside the aircraft advanced model

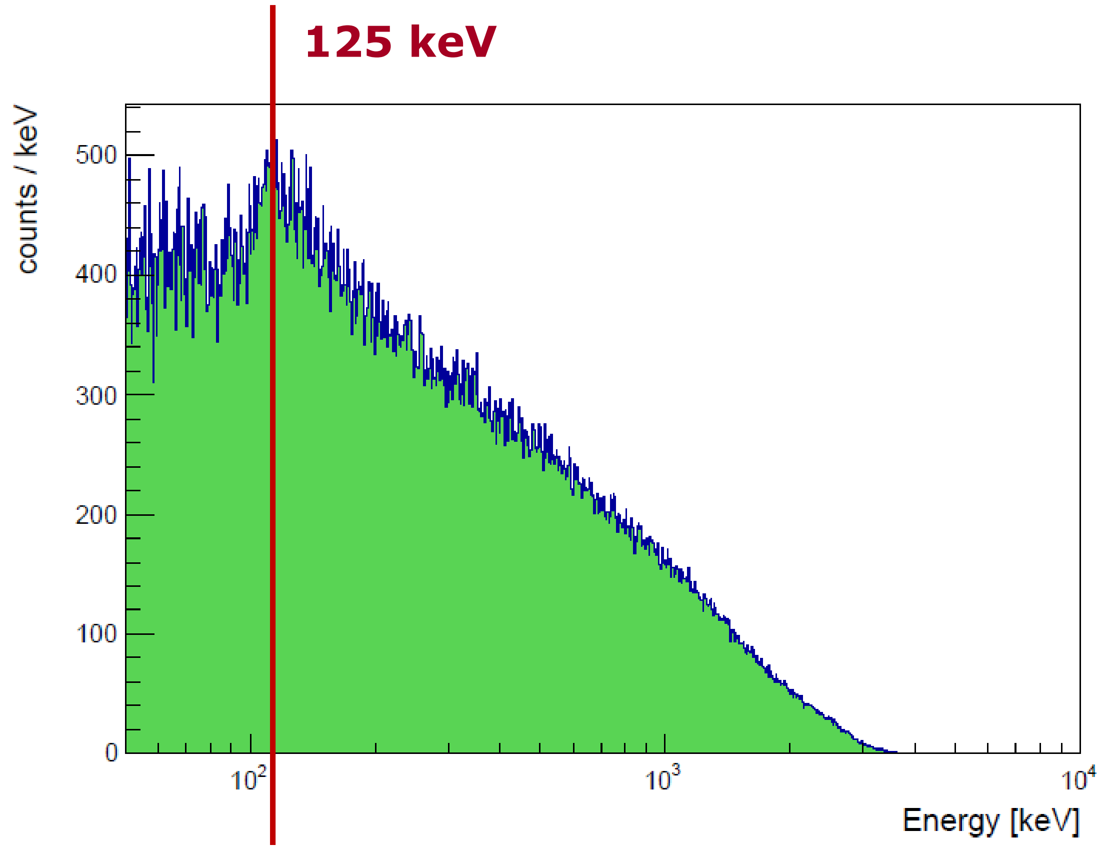


Figure 25: Energy spectrum representation of the recorded energy of a medium intensity TGF inside a human model volume, obtained by MEGALib.

- D = E/m (Gy)
- E = Triggered events x Average weighted energy
- H = D x Wr (Sv)

Average weighted energy = 125 keV;
m = 80 kg;
Wr = 1

Effective dose results

DISTANCE (km)	EFFECTIVE DOSE (mSv)	
	AVERAGE TGF	STRONG TGF
5.0	**1.4×10^{-4}**	**5.9×10^{-1}**
2.5	**5.6×10^{-3}**	**2.0×10^{1}**
0.5	**3.8×10^{-1}**	**2.1×10^{2}**

Table 1: Effective doses for the human model inside the aircraft advanced model.

D = E/m (Gy)

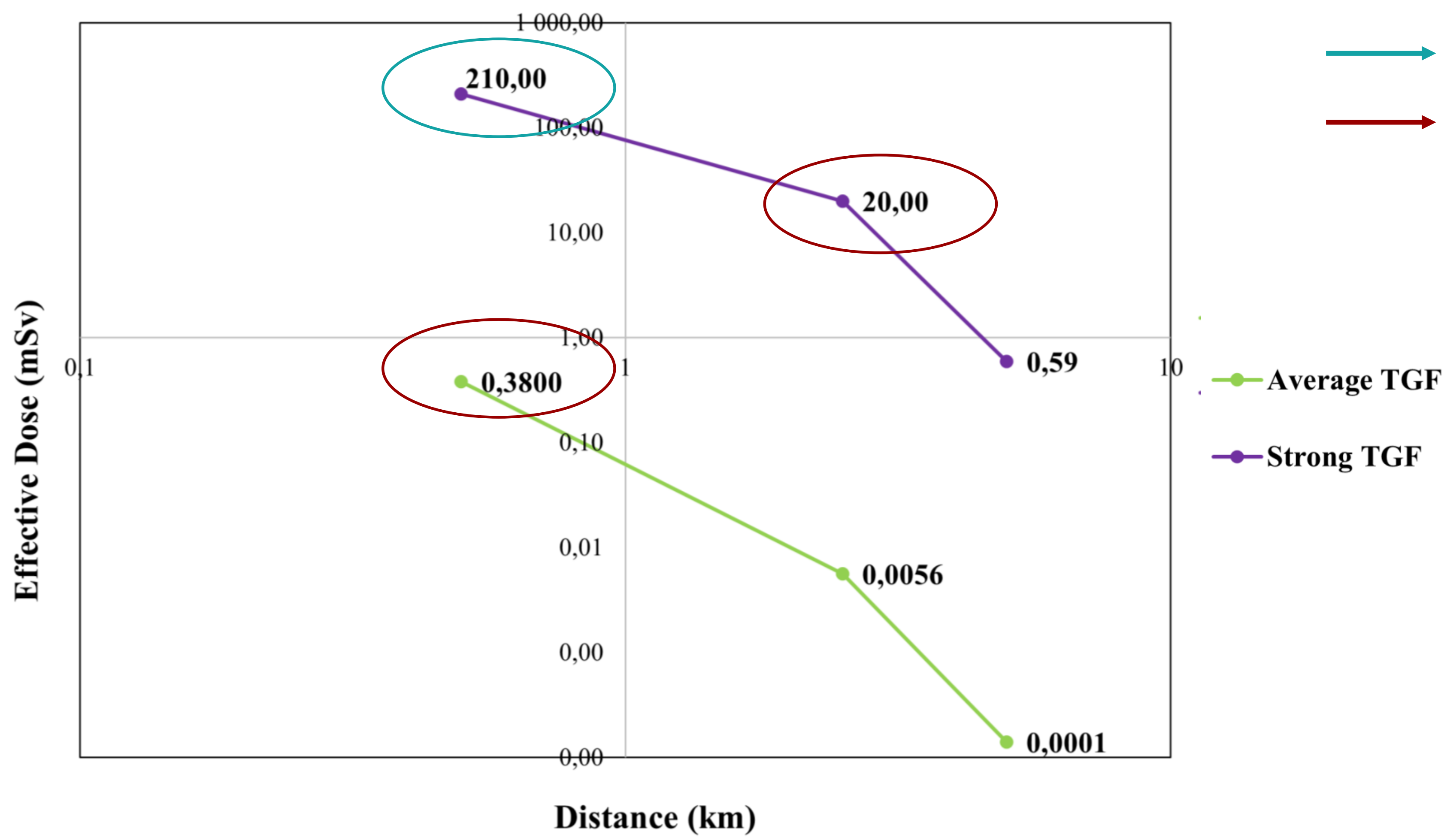
E = Triggered events x Average weighted energy

H = D x Wr (Sv)

Average weighted energy = 125 keV;
m = 80 kg;
Wr = 1

Exposed workers: 50 mSv/year
General public: 1 mSv/year

Effective dose results



Exposed workers: 50 mSv/year
General public: 1 mSv/year

Figure 26: Effective doses for the human model inside the aircraft advanced model.

CdTe TGF Monitor

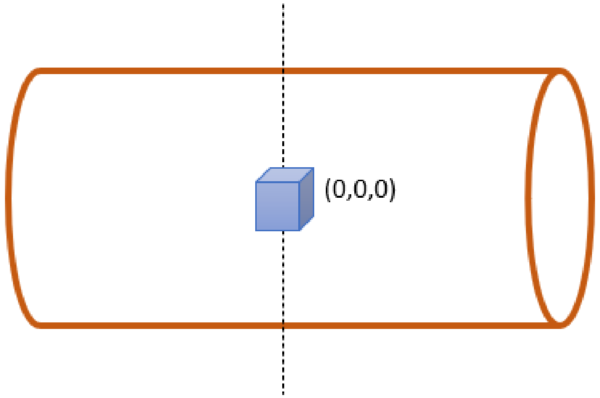


Figure 27: Diagram for the 1 cm edge CdTe detector, placed inside the aircraft advanced model.

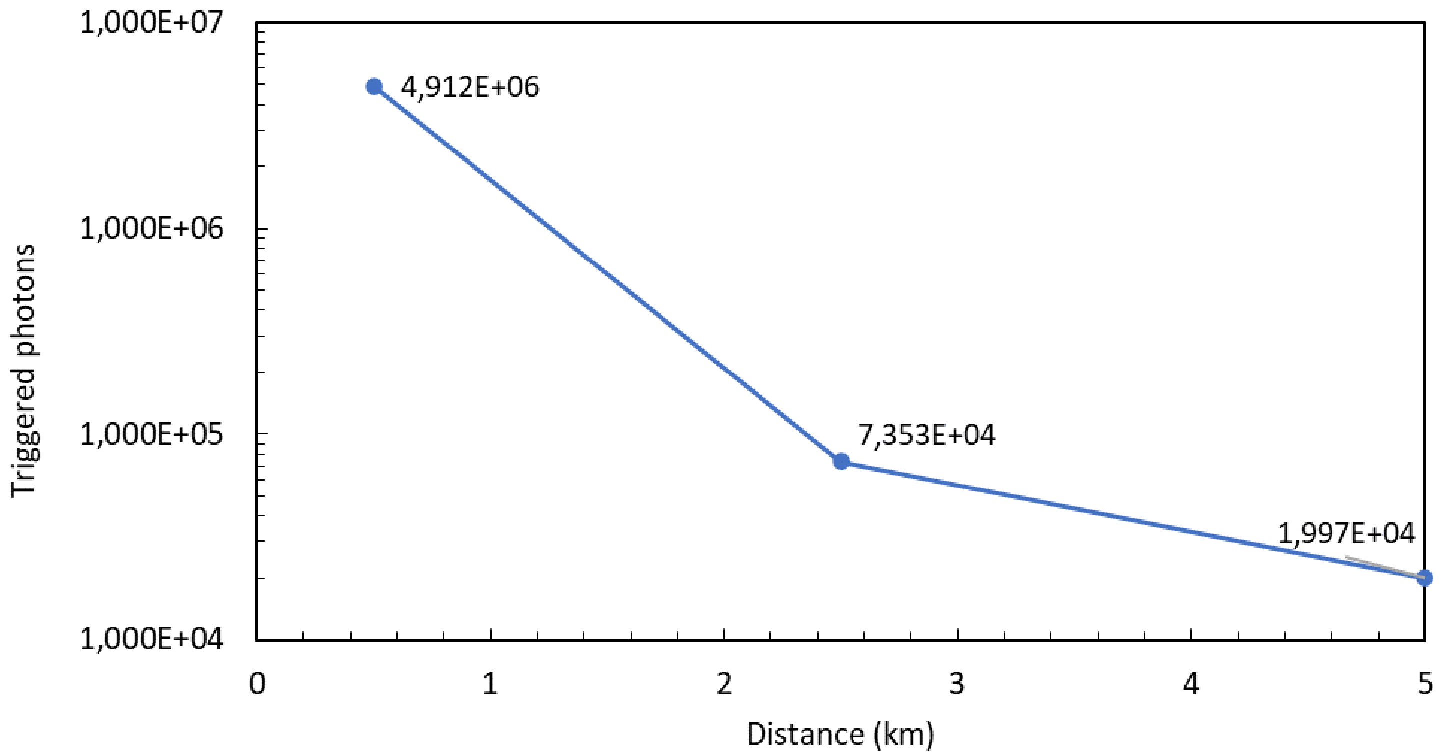
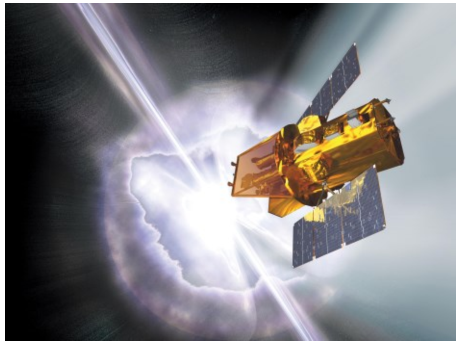


Figure 28: Triggered photons for a linear extrapolation to 100 µs considering a cone beam incident on the CdTe detector, inside the aircraft advanced model.

Space Rider



High-energy Astrophysics Instrumentation:

- Radiation ageing/hardness in active mode (Space Exposure Locker if possible);
- Some astrophysics measurements/calibrations: Crab Nebula or GRB (if lucky).

TGF Science and Aviation Safety:

- TGF polarization: outstanding scientific measurement;
- TGF monitor test: potential for a commercial aircraft safety product (Spark4Tech call).

CdTe Prototypes: TGF Monitor Preliminary Design

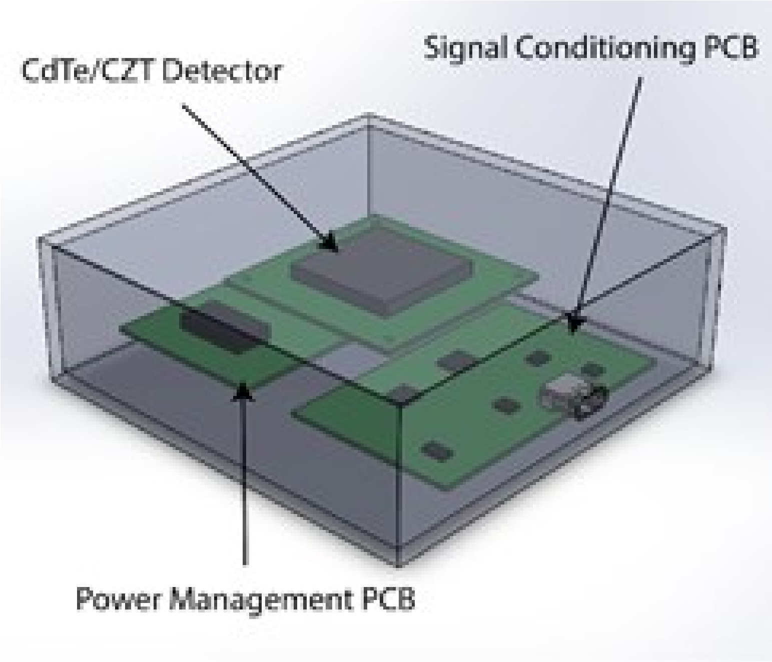


Figure 29: TGF Monitor prototype (5 mm thickness, 8x8 pixels, total 2.56 cm^2 area). 150 x 150 x 50 mm case with power-supply and data collection are made via the USB port on the side.

Conclusions

- The established limits for the effective dose per year will be exceeded in the case of a strong TGF for an exposed passenger up to over 2.5 km distance and for a crew member for distances over 500 m away from the emission center;

- For a medium intensity TGF, the aircraft passengers should be informed of a TGF irradiation with its emission site at circa 500 m;

- Airlines and pilots should circumvent cumulonimbus clouds to avoid any risks of direct irradiation or lateral TGF emissions.

Future work

- The effect of neutrons and the neutron impact on the absorbed dose;
- New set of improved detail in simulation’s elements considering the human body as well as glass window and the composites in the aircraft structure;
- Measurements at flight altitudes by using a radiation detector on board a commercial, military or scientific aircraft;
- Measurements with Space Rider.

Thank you!

Questions?

joanamingacho@gmail.com