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Using Flight-Time to Contextualize Radiological Dose

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During every moment of our lives, we are surrounded by radiation from natural and manmade sources. Our bodies contain radionuclides from which we receive radiation. Radionuclides are found in the foods we eat and in the ground we walk on. We receive cosmic radiation from space. Radionuclides are also found in the airborne particles we breathe. The radiological dose from all these sources is termed background dose. Many of us are unaware of the radiation around us. Radiation is as much a part of our daily lives as air and water. In this article, time spent flying in an airplane is used as an analogy to contextualize radiological dose.

For many people, the simple mention of radiation conjures feelings of fear and danger. Mass media coverage of radiation events only intensifies our emotional reactions. Adding to this is that the units quantifying radiation—grays, sieverts, rads, and rem—are typically unfamiliar. Thus our feelings often result in an attitude of “no matter how small the value, it is too high.” Adoption of a “zero-tolerance” position is not surprising given the limited knowledge of radiation. Yet, we are surrounded by radiation in our daily lives. Radiation is part of the natural environmental fabric we live in. This makes a zero-tolerance position on radiation unrealistic.

There are many approaches to help people relate to and understand unfamiliar subjects. One approach is to teach by analogy: to provide a suitable comparison that allows us to relate the new topic to something we already understand and accept. Here time, more specifically time spent flying in an airplane, is used as an analogy to contextualize radiological dose and its associated unit, the millisievert (mSv).

**Flight-time equivalent dose**

The concept of flight-time equivalent dose (FED) relates time spent in a jet airplane during flight with radiological dose. In fact, time is already used in a similar manner to help us relate to very large distances: the light-year! Time is a very useful comparator. It is universally well understood and its units provide good resolution: seconds, minutes, hours, days, and so on. Time can readily be used to convey numerical values that are orders of magnitude apart. For example, the difference between one second and 10 hours is immediately obvious, but should this difference be expressed only in seconds as the difference between one second and 36,000 seconds, or similarly in millisieverts as the difference between $2.78 \times 10^{-8}$ mSv and 1 mSv,

![Effective dose rate as related to latitude.](image1)

Fig. 1. Effective dose rate as related to latitude.

![Radiological Dose Comparison Chart](image2)

Fig. 2. Radiological dose comparison chart.
Cosmic dose rate increases with altitude above Earth's surface. In fact, for every 1830-m increase, the cosmic dose rate doubles. At the commercial aircraft cruising altitude of 10,000 m, the cosmic dose rate is approximately 0.004 mSv h\(^{-1}\), about 15 times greater than the dose rate at Earth's surface. Therefore, the dose received from a dental x-ray can similarly be expressed as the dose received during 2.5 flight-hours.

Alternatively, dose can be represented as a multiple of another dose. The dental x-ray discussed earlier could be used as the basis for analogy. Thus, a typical 0.1-mSv chest x-ray could be expressed as being equivalent to 10 dental x-rays. While true, the patient experience in receiving a dental x-ray and a chest x-ray is quite similar. There is little to suggest to the patient that one experience results in a received dose that is tenfold greater than the other. Additionally, expressing dose only in terms of another dose provides no context to life experiences that might otherwise assist in relating the understanding of radiation or its associated units.

Time spent flying in an airplane represents an activity of a finite duration, provides a readily imaginable context, and is well understood, even for individuals who have not experienced flight themselves. Thus, FED is chosen as the preferred analogy for dose comparison.

### Dose rate derivation

As with dose rates at Earth's surface, dose rates from galactic cosmic radiation vary. To use FED as an analogy, a dose rate at cruising altitude needs to be defined. Much work has been done to study cosmic dose rates. Friedberg and Copeland write that the Earth is continuously irradiated from all directions by high energy charged particles of galactic cosmic radiation.... At the geomagnetic equator where geomagnetic field lines are parallel to Earth's surface, only particles equal to or greater than 100 MeV can reach Earth's atmosphere. Moving from the geomagnetic equator towards a magnetic pole, the field lines gradually become perpendicular to the Earth's surface and therefore more parallel to the trajectories of the incoming ions, and more ions enter the atmosphere. At the magnetic poles, field lines are perpendicular to Earth's surface and ions of any energy can reach Earth's atmosphere.

Friedberg and Copeland plotted the effective dose rate at 20°E longitude, as related to geographic latitude (reproduced in Fig. 1, with modifications). Dose rates in the figure are calculated for mean solar activity during the period January 1958 through December 2008. If one were to fly an aircraft at a constant altitude from the geomagnetic equator towards the north or south magnetic pole, the dose rate would increase with distance from the equator.

The ideal altitude for long-range commercial aircraft
flight is dependent on atmospheric conditions and on aircraft weight. This typically ranges between 9000 m and 12,000 m. Shading to highlight this region has been added to Fig. 1. An estimate of the dose rates at an altitude of 10,000 m has also been added. Although effective dose rate varies with geographic latitude and solar activity, a representative effective dose rate of 0.004 mSv h⁻¹ (shown in red) at a typical cruising altitude of 10,000 m has been assumed as a basis for FED comparisons. Supporting this choice is the fact that the northern air routes are the busiest.⁵ This aligns with the values presented in similar reporting.⁶⁻⁸

Dose comparisons and limitations

With the establishment of a representative dose rate at flight altitude, activities resulting in radiological dose to individuals during their daily lives can be put into context. Two figures have been created to illustrate the application of FED. Figure 2 illustrates radiological dose received from common activities; the concept of FED is shown in the infographic in the bottom right corner. Figure 3 focuses on the dose received from a wide range of medical procedures. The areas of the representative circles are proportional to the dose received during the named activity or procedure. This permits quick visual comparison between doses while FED provides the context of a relatable life experience in flight-hours, time spent flying in an aircraft required to receive an equivalent dose. Figure 3 illustrates that medical procedures are large potential contributors to the dose we receive. Note that all doses presented in these figures are typical for their associated activities. Actual received doses may vary substantially depending on many factors such as location, equipment used, protocols in place, etc.

A few decades ago, banana equivalent dose (BED) was suggested as a whimsical way to contextualize dose. It has gained some popularity as a communication tool. The estimated dose from eating one average-sized banana is 0.1 µSv.⁹ Radioactivity in the banana comes from the potassium isotope ⁴⁰K. Dose uptake from ingested material is referred to as committed dose; however, through homeostasis, the human body sheds excess potassium. Thus, the dose from any excess potassium in the body (such as from eating many bananas at once) will only be received until that excess is shed. In comparison, FED is received from galactic cosmic radiation and is composed of penetrating ionizing radiation similar to an x-ray. Additionally, the effects of FED are cumulative, and thus, FED provides a better comparison to effective dose.

When illustrating higher values of FED, flight-days, flight-weeks, flight-months, or flight-years could be used. However, commercial air flight is experienced and best understood in units of hours. Thus, the context starts to break down when trying to use FED to convey high doses. For example, an astronaut on a six-month mission on the International Space Station will receive a dose of approximately 18,000 flight-hours, which is likely understood as a long time, but its context is abstract. Alternatively, it could be expressed as a dose of two flight-years, but the idea of two years of continuous air flight is also abstract. It may be more appropriate to make the comparison that the dose received by the astronaut is approximately equivalent to the dose an airline pilot would receive during a 24-year career. Likewise, FED has limited value in contextualizing lethal dose as the flight-time required to receive a lethal dose is longer than the average human life. Approximately 140 flight-years are required to receive a lethal dose of 5 Sv.
Conclusions

Exposure to low levels of radiation originating from a variety of common sources is characteristic in daily life. The resulting potential for effect on health is most often expressed in abstract scientific terminology and notation. The concept of flight-time equivalent dose, which relates radiation exposure to time spent in an airplane during flight, will hopefully provide a versatile, accessible context for initiating and evaluating communications about radiation and dose in a relatable fashion. This may make it possible for the general public to gain understanding of radiation. It may also help support interdisciplinary communication on this topic.

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References


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