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Flight-Time Equivalent Dose – A Concept to Contextualize Radiological Dose

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Abstract

People are exposed to low levels of radiation every day from many sources including natural radioactivity in soil, rocks, air, food and from cosmic rays. Medical procedures, flying in an airplane, elements within our bodies and even some objects around the house may additionally expose people to small amounts of radiation.

The International System of Units (SI) uses the sievert (Sv) as the unit to express the health effect of low levels of ionizing radiation. The sievert, however, is not a commonly understood unit.

The worldwide population-weighted average annual effective dose from natural sources of radiation is approximately 2.4 mSv per year [1]. At sea level, approximately 17% of the dose is due to cosmic radiation entering the earth's atmosphere from space. From the earth's surface, cosmic radiation will typically double with every increase of 1800 m in altitude. Thus, an individual flying in a commercial jet airplane at an altitude of 10 000 m will receive more radiological dose than an individual on the earth's surface.

By relating the dose received during a commercial flight at altitude to the time spent on the flight, radiological dose from a large variety of sources can be expressed in the more readily understood context of time. For example, an individual flying in an airplane at 10 000 m will receive an average radiological dose of approximately 0.004 mSv per hour, thus a dose of 0.004 mSv is approximately equivalent to a flight-time equivalent dose (FED) of 1 hour. Similarly, the annual worldwide average natural background radiation of 2.4 mSv can be expressed as approximately equivalent to an FED of 600 hours, and a 0.01 mSv dental x-ray as an FED of 2½ hours.

The concept of FED provides an excellent benchmark to contextualize radiological dose, especially in communications with the general public. Using this concept, radiological dose can be expressed in readily understandable units of time spent in an airplane at altitude.

Introduction

One challenge in communicating radiological concepts with the general public is that units of radiation are not readily understood. The simple mention of radiation often conjures feelings of fear and danger. Include some units into the discussion: grays, sieverts, rads or rem, and no matter how small the value, it is perceived to be too high. Frequently, the general public associates communication involving radiation with risk. Adoption of a “zero-tolerance” position, given that the general low understanding of radiation is typical, is not surprising.

In our daily lives, however, we are surrounded by radiation from many sources, both natural and man-made, making a zero tolerance approach to radiation unworkable. Radiation is well understood by the industry, but not the general public. Providing a suitable comparison to assist the general public in the contextualization of radiation may prove to be advantageous in the communication of radiological risk. The concept of FED addresses this issue.

Flight-Time Equivalent Dose

FED is based on a simple idea which equates time spent in an airplane at altitude to a given radiological dose. In fact, time is already used in a similar fashion to measure distance: the light-year! Using time is very useful in this context as time is universally well understood, and provides good resolution (seconds, minutes, hours, days, years). Time can readily be used to convey numerical values which may be 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 1 second and 36 000 seconds or similarly in millisieverts as the difference between 2.77×10^{-8} mSv and 1 mSv, the understanding becomes more abstract.

So how can time be used to convey dose? Dose can be expressed as a time-equivalent unit by dividing a known dose such as the dose received from a panoramic dental x-ray (0.01 mSv [2]) by the dose rate received during a known activity. Natural background dose could be used. The average worldwide natural background dose at the earth’s surface is approximately 2.4 mSv per year [1] or 2.7×10^{-4} mSv/h. Thus, the dose received from the dental x-ray is equivalent to the dose received during 36.4 hours of average terrestrial activity. Cosmic dose at commercial aircraft flight altitude can also be used. The typical dose rate in a jet airplane at an altitude of 10 000 m is approximately 0.004 mSv/h [3]. Therefore the dose received from the dental x-ray is equivalent to an FED of 2.5 hours. FED provides a better dose comparison than terrestrial-time as flying in an airplane is an activity we choose to do, has a finite duration and is thus more relatable.

Dose rate derivation

As with dose rates at the earth’s surface, dose rates from galactic cosmic radiation vary. Friedberg and Copeland [3] 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 [3] plotted, “the effective dose rate at 20°E longitude, as related to geographic latitude [reproduced in Figure 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.”

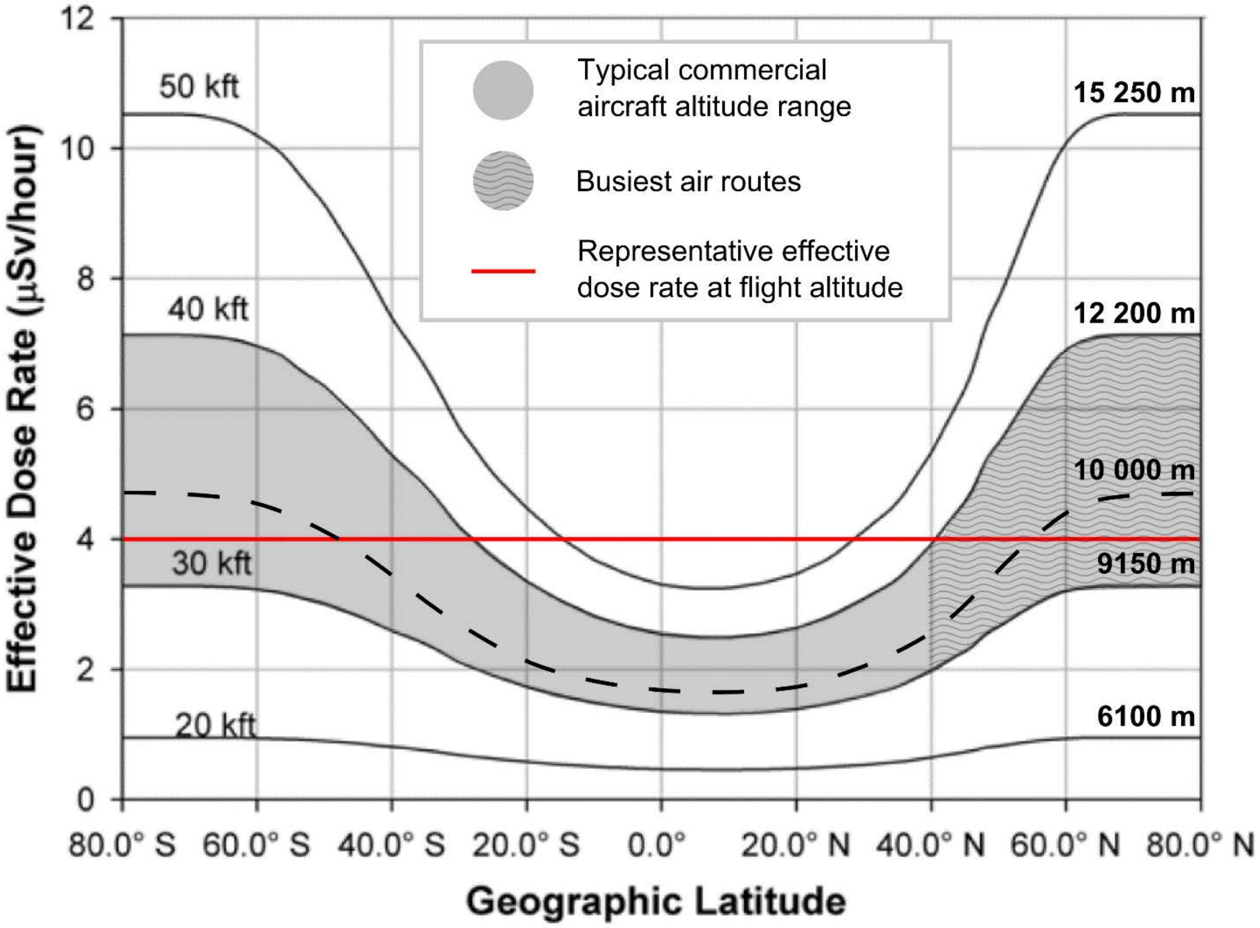

Figure 1 Effective dose rate as related to latitude [3]

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 Figure 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 (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 many of the busiest air routes utilize northern routes [3]. This aligns with the values presented in similar reporting [4], [5] and [6].

Dose Comparisons and Limitations

Two figures have been created to illustrate the application of FED. Figure 2 illustrates radiological dose received from common activities and sources, whereas 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 stated activity or procedure allowing for a quick visual comparison between doses. Both of these figures illustrate that medical procedures have become the largest potential contributors to dose received by humans. The doses presented in these figures are typical for their associated activities. Actual doses may vary.

Over the past few decades, banana equivalent dose (BED) has gained some popularity in contextualizing dose. It is estimated that dose received from eating one average-sized banana is 0.1 µSv [7]. Radioactivity in the banana comes from the potassium isotope ^{40}K. Dose uptake from ingested material is referred to as committed dose; however, through homeostasis, the human body sheds excess potassium, thus ingesting multiple bananas does not give a cumulative dose effect. In comparison, FED is received from galactic cosmic radiation and is composed of penetrating ionizing radiation similar to an x-ray. Unlike BED, the effects of FED are cumulative, and thus, FED provides a better comparison with effective dose.

The author has chosen to illustrate higher FED values in hours rather than in days, weeks, months or years for the reason that air flight is experienced and best understood in units of hours. While FED can effectively be used to contextualize low to medium levels of radiological dose, 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 FED of approximately 18 000 hours. Here again, a duration of 18 000 hours is an abstract concept. It could be expressed as a FED of 2 years of continuous air travel, but it is unlikely that anyone will spend 2 continuous years in flight. It may be more appropriate to make the comparison that the dose received by an astronaut during a six month mission on the space station 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. Coincidentally, however, assuming lethal dose to be 3.5 Sv, lethal dose is approximately equivalent to 100 years FED!

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 exposures to time spent in an airplane during flight, provides a versatile, more accessible context for evaluating and talking about these phenomena in a standardized fashion.

This concept not only makes it possible for the general public to understand and feel less threatened by complex language, it may also help support inter-disciplinary communication on this topic.

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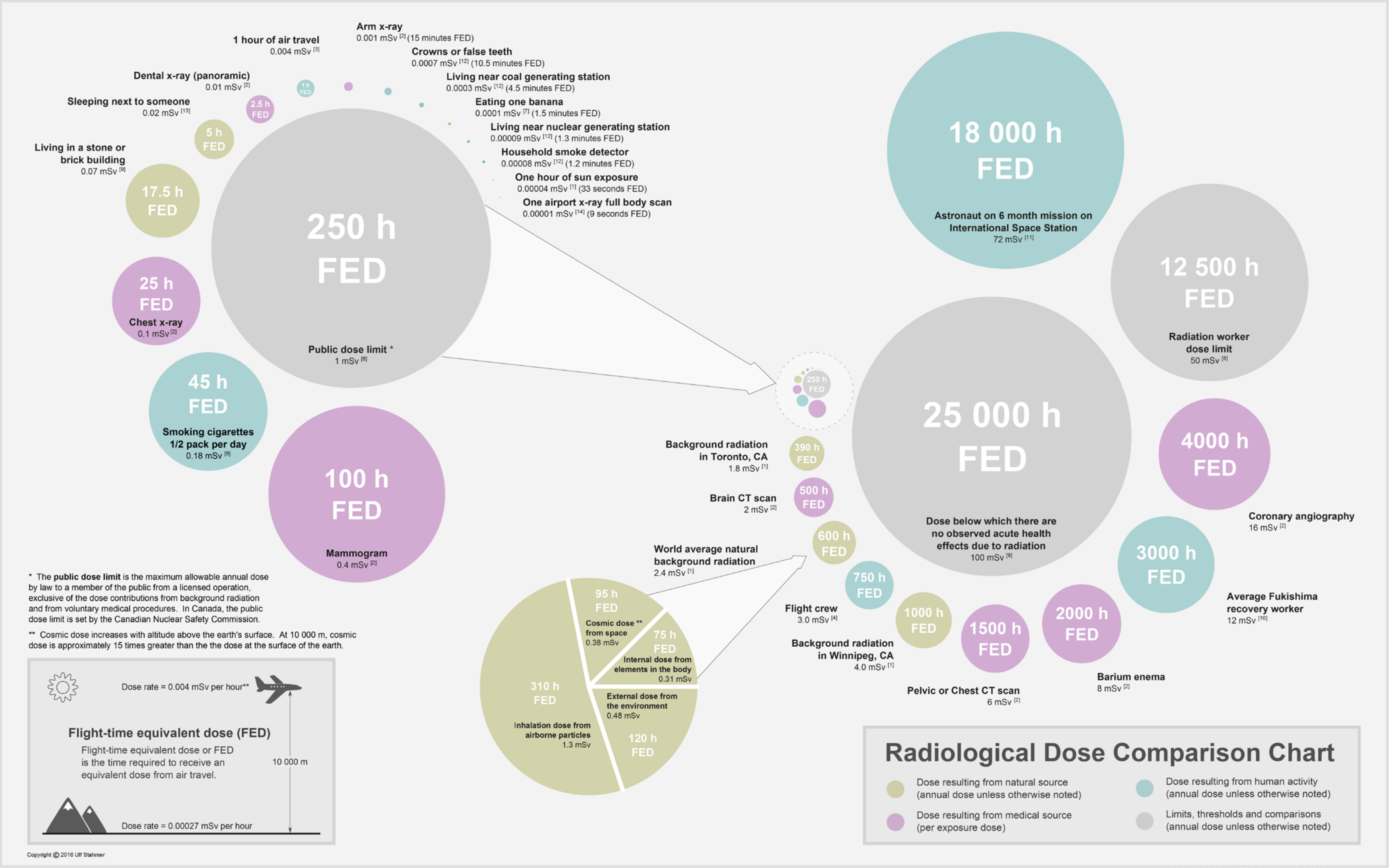


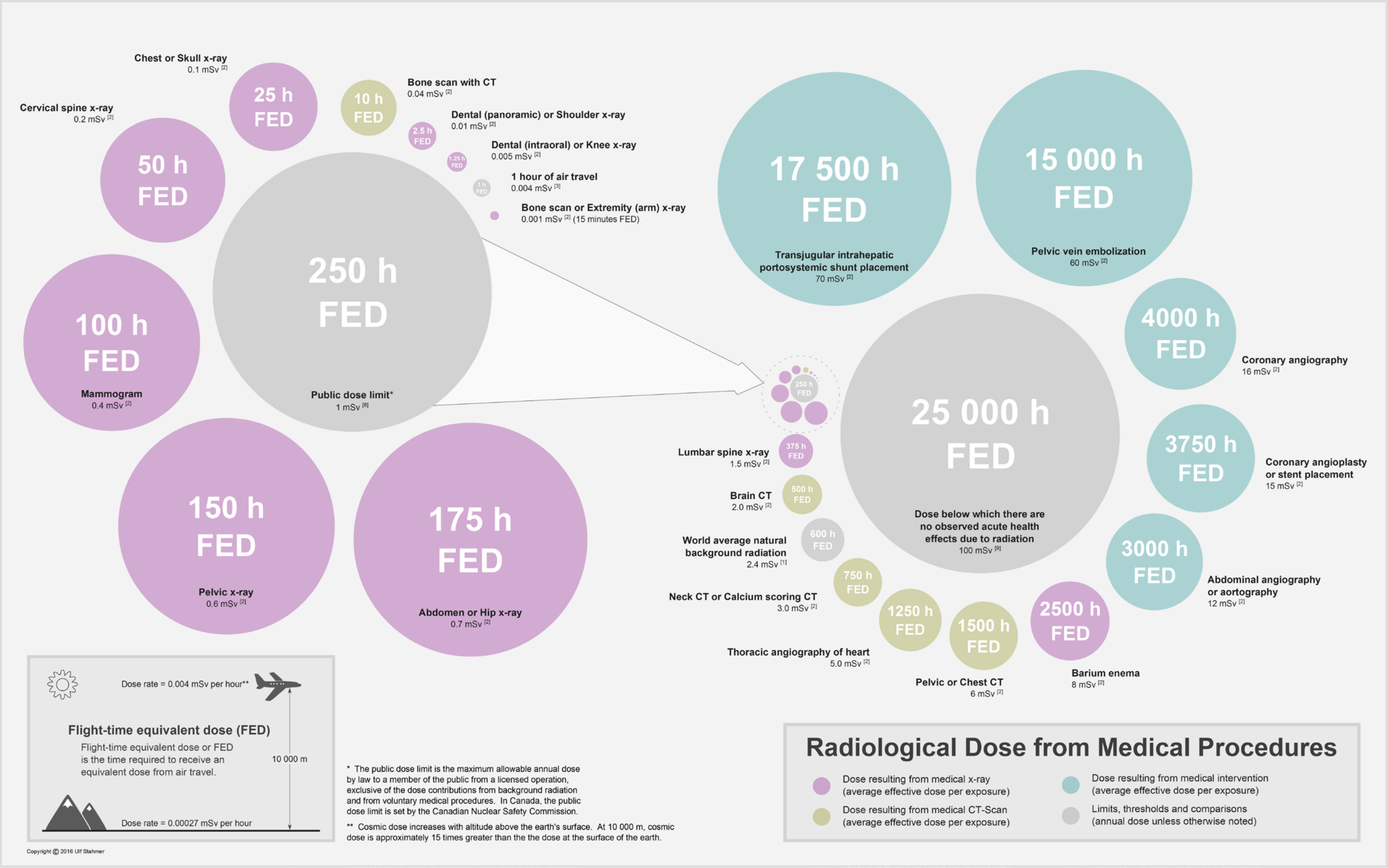
* The **public dose limit** is the maximum allowable annual dose by law to a member of the public from a licensed operation, exclusive of the dose contributions from background radiation and from voluntary medical procedures. In Canada, the public dose limit is set by the Canadian Nuclear Safety Commission.

** Cosmic dose increases with altitude above the earth's surface. At 10 000 m, cosmic dose is approximately 15 times greater than the the dose at the surface of the earth.

Flight-time equivalent dose (FED)

Flight-time equivalent dose or FED is the time required to receive an equivalent dose from air travel.

Figure 2 Radiological Dose Comparison Chart



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- ● Dose resulting from medical x-ray (average effective dose per exposure)
- ● Dose resulting from medical CT-Scan (average effective dose per exposure)
- ● Dose resulting from medical intervention (average effective dose per exposure)
- ● Limits, thresholds and comparisons (annual dose unless otherwise noted)

Figure 3 Radiological Dose from Medical Procedures