Measurement averaging considerations on appropriate specification of exposure limits for radiofrequency electromagnetic fields

Australian Radiation Protection & Nuclear Safety Agency, Lower Plenty Road, Yallambie VIC 3085

This document is intended to provide additional information associated with the formulation and technical specification of the ARPANSA draft

For any given biological effect there will be an associated interaction mechanism and it is important that harmful interaction mechanisms are adequately accounted for the expression of relevant exposure limits. In particular, for any potentially harmful agent there will be relevant parameters of time and space that will have a major influence on the degree to which a biological interaction can occur and upon the nature of any effect.

Firstly, when specifying limits to protect against the harmful effects of an agent it is essential that measurements to ensure compliance are performed on a time scale that matches the rate for which the effect is known to occur. For example, suppose that a limit were to be set to protect against the harmful effects of drinking too much water. It is not sufficient to state a quantitative limit for consumption of water, say, 10 litres of water - unless a relevant measurement time scale is defined for the limiting quantity. It may be harmful to drink 10 litres of water within a time span of less than 10 minutes. However, nobody would seriously suggest that the consumption of up to 10 litres of water would be harmful over a long period of time (say one day) consistent with the rate at which water dissipates from the body. Clearly, the time scale must either be shorter than, or must closely match, the time scale associated with accumulation and dissipation of any harmful effects.

Secondly, exposure limits also need to take account of the spatial character and interaction mechanics of any harmful agent. For example, while it may be safe to consume a certain quantity of water within a given time, we would implicitly recognise that the water will dissipate from the stomach via the blood stream to the body as a whole and that any excess will eventually be excreted. However, apart from dosage to the stomach via drinking the water, it is likely to be highly dangerous to deliver a similar quantity of water to a single arbitrary organ within a similar period of time.

It follows that, aside from choice of a suitable measurement quantity and its associated magnitude, the adequacy of an exposure limit will depend on the unambiguous specification of appropriate temporal and spatial averaging parameters. Such parameters must be chosen to be consistent with likely injury processes[1].

Regardless of any other postulated effects, it is known that the absorption of radiofrequency energy within the body will generate heat. Heat will accumulate in different tissues according to various factors related to the frequency of the radiation and the geometry of the exposure in relation to the applied fields. In addition to RF absorption characteristics of various tissues, the evolution of elevated temperature profiles within the body will be mitigated by various

[1] Exposure limits must also prevent other unpleasant effects. Examples of such effects are the hearing effect associated with pulsed microwave fields and electro-stimulation shock effects associated with contact currents at low frequencies.

cooling mechanisms such as thermal conduction, blood flow, respiration and perspiration, etc.

Figure 1 indicates how the appearance of a cumulative injury process associated with a near instantaneous injury threshold may give the false impression of being directly related to absorbed dose. For example, the dotted line in figure 1 indicates a short term SAR exposure threshold above which thermal injury will begin to occur. Whenever the instantaneous exposure SAR level exceeds the particular injury threshold, a thermal injury will begin to occur immediately when tissue temperature has reached a critical level. The extent of the injury will depend on the time it takes for particular tissues to be heated, the volume of tissues involved, and the number of repeated bouts of excess heating, etc.

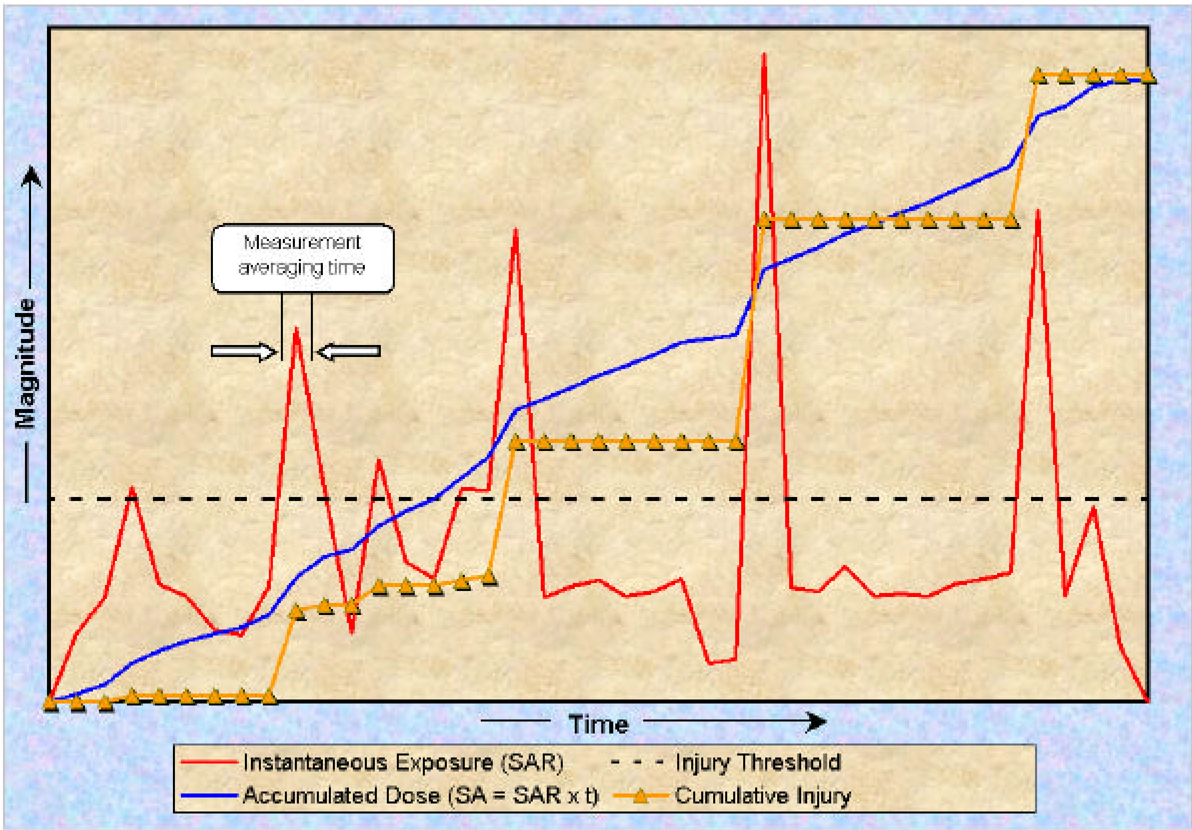

Figure 1 For threshold effect injury processes such as those mediated by heat the measurement averaging time must be sufficiently short to adequately reflect the likely injury mechanism.

Figure 1 also indicates the critical importance of understanding the temporal nature of a biological interaction mechanism and at least matching the measurement averaging time to that of the fundamental injury process. For example, there is an apparent correlation in the data of figure 1 between cumulative injury and accumulated dose. Hence, without actual knowledge of the injury mechanism, it is possible to mistakenly conclude that the observed injury is related to dose acquired over a long period of time[2].

2 The early exposure limits of some eastern European countries were apparently intended to be averaged over long periods of time (an eight hour working day or longer) and appear to be based on a similar incorrect analysis of relevant interaction processes.

Referring to figure 1 and allowing for an additional safety factor, the value of the relevant exposure limit must be set below the threshold value and the averaging time specified for measurement must be the same as, or shorter than, time scales associated with the injury process. In the event where a potentially harmful effect is not clearly understood, a conservative approach may be taken through the adoption of the shortest practical measurement averaging time where the averaging time chosen is likely to be shorter than the time constant associated with the injury process.

Far field exposure situations at frequencies below 10 GHz generally involve relatively large “hot spots” and the heat load on the whole body is generally the major constraining factor. In such circumstances, a measurement averaging time of around six minutes is quite adequate. However, at high frequencies, absorption of RF energy is restricted to relatively small volumes of tissue near to the surface of the body. In such circumstances, heating can be quite rapid and progressively shorter measurement averaging times (seconds rather than minutes) are invoked to prevent injury with exposure to frequencies above 10 GHz.

Figure 2 illustrates the conservative nature of the ICNIRP 1998 guidelines (NZS 2772.1:1999) at high frequencies relative to some other recent standards. The decrease in averaging time at high frequencies is necessary to prevent injury to the skin.

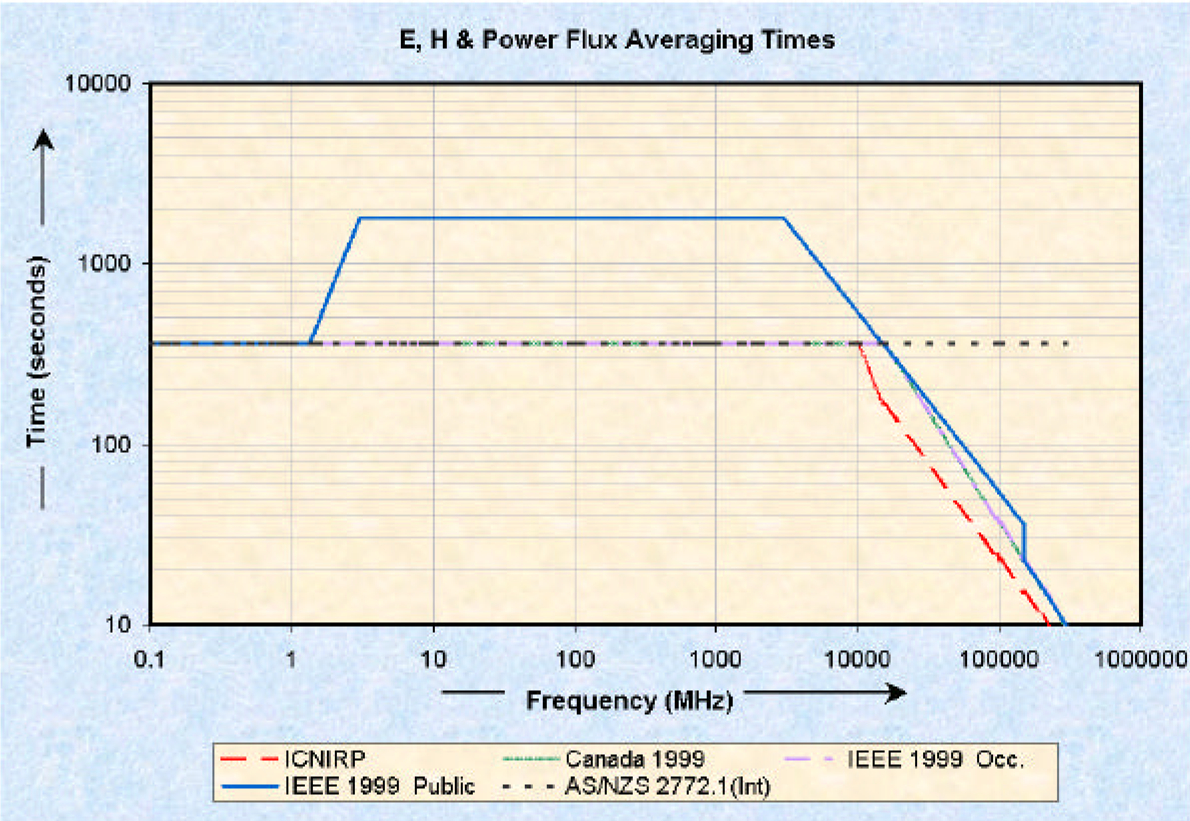

Figure 2 Comparison of averaging times specified in recent standards.

In addition to effects of exposure in the “far field”, close proximity exposure to high power radiators at frequencies below about 10 MHz can produce contact or arc-over currents resulting in RF shock and burns and also, for frequencies below about 100 kHz, the direct electro-stimulation of nerves. Such effects occur in very brief time intervals. Relevant measurement time scales must therefore be sufficiently short to account for such effects. For this reason, the averaging times used for low frequency (under 100 kHz) current effects leading to possible electro-stimulation of nerves are selected to be as short as practical (100 microseconds corresponding to the minimum reaction time of nerve cells).

Similarly, to prevent unwanted side effects associated with pulsed fields, an averaging time of 50 microseconds is used in the specification of the localised SA level to the head.

Finally, the spatial averaging volumes for both localised SAR in the body and SA within the head are restricted to 10 gram of tissue mass on the basis that this is marginally less than the smallest tissue volume over which any adverse thermal effect is likely to occur.

In summary, the adequacy of health related exposure limits depends heavily upon the proper selection and specification of both temporal and spatial measurement conditions where the relevant factors must be deduced from a thorough understanding of both physical and biological interaction mechanisms. Conversely, it is not sensible to give protective limits based on prospective adverse health effects unless relevant interaction mechanisms can be reasonably hypothesised and understood. Failure to meet such conditions is likely to result in an inappropriate specification, both in terms of the appropriate magnitude, the choice of limiting quantities, and also the required temporal and spatial measurement averaging specifications. Finally, it follows that arbitrary exposure limits designed to protect against health effects for which there is little understanding of basic interaction mechanisms would not necessarily be protective. Any such ad hoc limits would be prone to improper formulation through adverse selection of limiting quantities and/or incorrect choice of spatial and temporal measurement parameters.

References

1. ARPANSA draft for public comment "*Radiation Protection Standard - Maximum Exposure Levels to radiofrequency fields — 3kHz to 300GHz*", March 2001. Note: the draft document is available at: http://www.arpansa.gov.au/rf_dft_standard.htm