INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/638-17

College on Medical Physics: Imaging and Radiation Protection

31 August - 18 September 1992

Lecture notes

J. Cameron

Department of Medical Physics
University of Wisconsin, Madison
Wisconsin, U.S.A.

A RADIATION UNIT FOR THE PUBLIC

by John Cameron, Department of Medical Physics
University of Wisconsin, Madison, Wisconsin 53706

The public has an exaggerated fear of even small amounts of ionizing radiation, such as x-rays and radioactivity. The fear of radiation is made worse by not understanding the scientific words used to describe it. This article describes a radiation unit based on natural radiation that is easily understood by the public.

I propose a simple way to explain radiation. The quantity is called *ionizing radiation*, which will often be shortened to *radiation*. The new unit for ionizing radiation is time--"Background Equivalent Radiation Time" (BERT). BERT is the number of days, weeks, months or years that would give an adult the same "effective dose equivalent" from natural or background radiation. In calculating the BERT I suggest using an average background rate of 3 mSv (300 mrem) per year even though the background varies somewhat over the earth. (I thank my colleague Professor H.T. Richards for suggesting the name for the unit.) In describing radiation to the public BERT would not be mentioned. The amount of ionizing radiation would be expressed simply in terms of days, weeks or months of natural radiation. For example, compare the information in the following statements. "Your x-ray study gave you about *100 millirems or 1 mSv of effective dose equivalent*." OR "Your x-ray study gave you *radiation equivalent to about four months of natural radiation*."

It is easy to use the new unit. You have to remember that natural radiation to the public is about 300 millirem or 3 mSv per year. Once you know the effective dose equivalent in mSv or mrem you can figure the days, weeks, months or years of natural radiation. For example, the BERT for 1 mrem is roughly one day of natural radiation and the BERT for 1 mSv is about four months. Radiation that strikes only part of the body, such as medical x-rays, is not as hazardous as the same amount of radiation to the whole body. For example, 100 mrem to your lungs is equivalent to only 12 mrem of effective dose equivalent to the whole body. Other organs have similar factors to convert the dose equivalent to effective dose equivalent.

Typical BERTs of ionizing radiation from medical x-rays with this new unit are: for a dental bitewing, about one week; for a chest x-ray, about ten days; for a mammogram, about three months; and for a barium enema x-ray study, about one year. The values vary greatly from one medical center to another. The BERT for the average amount of radiation to the public each year from diagnostic x-rays is about seven weeks. Of course, some people receive much more than others. The BERT for the average amount of radiation we receive each year from nuclear power plants is less than one day of additional natural radiation even for people who live in the vicinity of a nuclear power plant. The BERT for a trans-Atlantic jet flight is about five days.

Dose Equivalent Out--Imparted Energy In

John Cameron
Lone Rock, Wisconsin

To the Editor:

I propose replacing the non-scientific radiation quantities *dose equivalent* and *effective dose equivalent* with the scientific radiation quantity *imparted energy* ε for all radiation protection purposes. My reasons for wishing to get rid of dose equivalent and effective dose equivalent are:

1. Dose equivalent is a questionable scientific quantity because of uncertainty in specifying the quality factor Q.[1]
2. Dose equivalent is of little interest in radiation protection as it usually refers to radiation to the outer portion of the body and in the case of medical applications, only to a portion of the body.
3. While effective dose equivalent is of interest in radiation protection it suffers from a double dose of biological uncertainty--both the quality factor Q and the organ weighting factors W_T are uncertain. Therefore, effective dose equivalent is questionable as a scientific quantity.
4. To calculate effective dose equivalent it is necessary to know the radiation dose to various organs--a difficult, almost impossible task.

My reasons for proposing imparted energy as the primary radiation protection quantity are:

1. Imparted energy is a logical quantity for radiation protection since for most radiation protection purposes it is the most relevant quantity related to radiation risk.
2. Imparted energy is a well-defined scientific quantity. It does not depend on biological constants that cannot be uniquely determined.
3. For diagnostic radiology exposures, the major source of man-made radiation, imparted energy is closely correlated with the effective dose equivalent.[2] That is, it provides the same basic information as effective dose equivalent in an understandable manner without using uncertain biological parameters.
4. Imparted energy can be calculated (and in some cases measured) with reasonable accuracy.
5. For diagnostic radiology exposures an instrument is already available that can give a reasonable estimate of the imparted energy.[3] The exposure-area product needs only to be corrected for the kVp and HVL. In diagnostic radiology exposures the imparted energy for a given exposure-area product is about 0.1 mJ/R cm^2 for 100 kVp and 0.05 mJ/R cm^2 for 50 kVp if the filtration is 3 mm Al.[4]
6. Tables and graphs of energy fluence for diagnostic x-ray beams are available.[4] The energy imparted is equal to the energy fluence times the exposed area.
7. The pyroelectric radiation dosimeter (PRD) can directly measure the energy fluence of a diagnostic x-ray exposure.[5]
8. For nuclear medicine exposures it is easy to calculate the imparted energy from the effective half-life of the radionuclide.
9. Imparted energy can be estimated for many occupational whole body exposures if the average energy of the radiation is known.

DISCUSSION

The idea of expressing diagnostic exposures in terms of energy imparted has received considerable attention over the last three decades.[6-12] Wall et al. state:[13]

> "A major advantage of the simple concept of the total energy to the patient is the ease with which it may be estimated even during complex x-ray examinations. The reasonable degree of correlation that is evident between energy imparted and health detriment for a wide range of x-ray examinations suggests that *in appropriate circumstances* it can represent a useful practical quantity for estimating risk to patients." (Emphasis in the original.)

The entrance skin dose (esd) is currently the most common quantity to express the dose to patients receiving medical x-ray exposures. The esd is often misleading as a measure of radiation risk. For example, a dental x ray has an esd about ten times greater than a PA chest x ray, but the imparted energy for the chest x ray is about twice that of a dental x ray. The imparted energy ε is highly correlated with the radiographic risk and the effective dose equivalent for the common radiographic projections.[14]

The usefulness of imparted energy ε as a radiation quantity was suggested by Bond et al. in their analysis of excess solid cancer deaths in Japanese bomb survivors.[15,16,17] They calculated the collective imparted energy ε_c to the various dose groups. They divided this value by the number of excess solid cancer deaths for each dose group to determine the imparted energy ε_o needed to produce one excess death from a solid cancer. For all dose groups above 0.50 Gy, about 3 kJ of imparted energy caused one cancer death. At doses below about 0.50 Gy the small number of excess cancer deaths did not permit the determination of ε_o. Three kJ is equivalent to about 50 Gy to a 70 kg person--about ten times the lethal dose for a typical adult. That is, ionizing radiation is much less effective for inducing cancer than for killing. At the low doses received by most occupational workers, the collective energy to produce one cancer death would be considerably larger than 3 kJ. At an annual dose of 1 mGy, it would take over 100,000 years for a person to accumulate 7 kJ, a conservative value for ε_o at this dose rate.

In explaining radiation to non-scientists, imparted energy should be expressed as the time it would take a person to

[continued]

receive the same ε from background radiation, excluding alpha particle radiation to the lungs. This people's radiation unit is called *Background Equivalent Radiation Time* or BERT.[18] The typical background imparted energy is about 1 mJ/kg per year.

There will be occasional situations where the imparted energy may not provide sufficient information for radiation protection purposes. For example, doses from high LET radiation or a large amount of radiation to a small volume of the body. In these cases it will be desirable to provide additional information about the characteristics and distribution of the radiation. This situation will occur rarely in occupationally exposed individuals. Radiation to the lungs from radon and its progeny should be kept as a separate problem. It is rarely a radiation risk to workers.

SUMMARY

I propose that imparted energy be used for all radiation protection purposes. Since it will probably take decades for the ICRU and the NCRP to adopt imparted energy as the quantity of choice for radiation protection, I recommend that, in the meantime, any published value of dose equivalent or effective dose equivalent should include in parentheses the imparted energy. If the radiation information is for the public, it should be expressed in terms of background equivalent radiation time or BERT. Radiation from high LET radiation should be kept as a separate problem. Unusual radiation protection situations should include details about the radiation and its distribution.

References:

1. National Council of Radiation Protection and Measurement (NCRP Report 104), p. 170 (1990)
2. B.F. Wall and F.W. Spiers, *Patient Dosimetry Techniques in Diagnostic Radiology* (IPSM Report 53—available from Medical Physics Publishing, 1-800-442-5778), The Institute of Physical Sciences in Medicine, York, England, p. 54 (1988)
3. P.C. Shrimpton, B.F. Wall, D.G. Jones and E.S. Fisher, *Phys. Med. Biol.*, vol. 29, 1199 (1984)
4. IPSM Report 53, p. 104 (1988)
5. A.A. Carvalho, S. Mascarenhas, M.H. dePaula and J.R. Cameron, *Med. Phys.*, vol. 19 (3) 575 (1992)
6. C. Carlsson, *Acta Radiologica Therapy Physics Biology*, vol. 1, 433 (1963)
7. C. Carlsson, *Acta Radiologica Therapy Physics Biology*, vol. 3, 311 (1965)
8. M. Gustafsson, *Acta Radiologica Diag.*, vol. 20, 123 (1979)
9. P.C. Shrimpton, D.G. Jones and B.F. Wall in *Proc. of Patient Exposure to Radiation in Medical X-ray Diagnosis*, Munich, April 1981, EUR 7438 (Commission of the European Communities, Luxembourg)
10. R.M. Harrison, *Phys. Med. Biol.*, vol. 28, 701 (1983)
11. P.C. Shrimpton and B.F. Wall, *Phys. Med. Biol.*, vol. 28, 1160 (1983)
12. G. Alm-Carlsson, C.A. Carlsson and J. Persliden, *Phys. Med. Biol.*, vol. 29, 1329 (1984)
13. IPSM Report 53, p. 55
14. IPSM Report 53, Fig. 7.4
15. V.P. Bond, V. Benary and C.A. Sondhaus, *Proc. Nat. Acad. Sc.*, vol. 88, 8666 (1991)
16. V.P. Bond, *When is a Dose not a Dose?* National Council of Radiation Protection and Measurement, NCRP Lecture No. 15 (1992)
17. V.P. Bond, *Radiation Effects Research Foundation Update*, Spring 1992
18. J.R. Cameron, *Physics and Society*, vol. 20, 2 (1991)