Radiation Protection Dosimetry
Vol. 98, No. 4, pp. 363-366 (2002)
Nuclear Technology Publishing

Guest Editorial

Dosimetry, Dosinference and Doswaggery

For ionising radiation, absorbed dose is defined as the energy imparted per unit mass of an infinitesimal volume. While straightforward to define, absorbed dose is somewhat more difficult to measure or infer. There is growing attention to the uncertainty in values of absorbed dose and its derivative quantities such as equivalent dose and effective dose. The process of arriving at a value of dose to record is variously called measuring a dose, computing a dose, calculating a dose, assessing a dose, evaluating a dose, estimating a dose, reconstructing a dose, inferring a dose, or doing dosimetry. All values for the quantity dose are based on some amount of inference, but the effect of the inference on uncertainty may range from trivial to enormous. The more inferential steps required to arrive at a dose value, the greater the uncertainty associated with the result. It is suggested here that the word dosimetry is being stretched too far when it is applied to inferential processes whose total uncertainty is little affected by measurement uncertainty, but is dominated by uncertainty in models, their parameters, and imputed data that have little or no basis in measurement.

DOSIMETRY

The word 'dosimetry' implies that one *measures* (whence the 'metry', from Greek *metron*, measure) something very closely related to energy per unit mass. There are many methods and devices used to measure radiation, including:

- observation of biological response (e.g. erythema)
- cloud chambers
- film blackening
- appearance of bubbles in superheated liquids
- analysis of activation or fission product yield
- scintillations
- observation of radiation damage (e.g. chemically etching damage in film, radiochromic changes, thermal and electrical conductivity changes)
- thermoluminescence (TL) or optically stimulated luminescence (OSL)
- chemical changes as quantified by light absorption or nuclear magnetic resonance
- measurement of electric charge or current in solids (Ge and Si) or gases such as xenon, P10, or air, and
- calorimetry.

Most of these measurement technologies are appropriate for placement outside the human body. However, the locations where we are interested in knowing or inferring absorbed dose are either on the surface of, or inside, the human body. For external irradiation, there are inferential steps between what quantity of energy is deposited inside the body and what quantity is measured by a dosemeter placed on the outside of the body. These inferential steps require information regarding absorption, scatter or albedo, and spectrum changes, based on knowledge or assumptions about the types, energies, and directions of incident radiation, as well as assumptions about the person wearing the dosemeter. Medical radiation dosimetrists evaluating doses for external beam radiation therapy are able to tailor the dosimetric calculations to the individual by using results from various modalities of medical imaging and other physical measurements. In the case of radiation protection dosimetry, the default position is to assume that people are like some mathematical or physical reference model, such as a phantom. For dose reconstruction, for epidemiology, and for dose reconstruction to be used in radiation injury litigation, a more individualised treatment may be required. For neutrons, there are still technical challenges in the actual measurement. For most low LET radiation, doses of the order of a milligray are accurately and precisely measured with today's technology.

Inferring absorbed dose due to external irradiation is relatively straightforward compared to the analogous inference for irradiation by radioactive material known or presumed to be inside the human body. One might argue that true *internal* dosimetry would require the surgical implantation of dosemeters in tissues, followed by their subsequent interrogation, either by removal and processing or by some non-invasive means. At present, such methods are usually only possible when small dosemeters are placed at various points within an anthropomorphic phantom.

DOSINFERENCE

Because uncertainties associated with the inferential steps often dwarf the uncertainties of the measurement steps*, inferring absorbed dose and related quantities following intakes of radioactive materials might more properly be called *dosinference* than *dosimetry*. The term dosinference is a blend of the words dose and inference. Measurements used for dosinference are often not of dose-like quantities, but of quantities that may be inferentially related to dose–rate-like quantities. For example, *in vivo* counting typically measures rates of interception of photons by detectors placed near the body. From such measurements, amounts of activity in various locations in the body are inferred at a given point in time. From measurements of radioactive material in excreta, the inference of activities in various tissues and organs is a much more tenuous business than it is for *in vivo* measurements.

Using activities inferred through *in vivo* counting, and knowledge or guesses of the time of intake, particle size and solubility for inhalation or chemical and physical form for ingestion, injection, intake through a wound, or dermal absorption from an ontake(1) of radioactive material, a time course of absorbed or equivalent doses to tissues and organs is inferred with the help of biokinetic models for Reference Man(2). Rarely, in radiation protection practice, are biokinetic models modified to account for individual differences from Reference Man. Several studies(3,4) have qualitatively described the uncertainties involved with the inference of doses from bioassay measurements and air samples. Two recent studies have evaluated uncertainty in biokinetic models(5,6). Intercomparisons of inferences of dose from intakes(7-10) have shown widely varying doses generated by different laboratories from identical data sets.

Doses from intakes can also be inferred from a combination of air sampling data, worker stay time, respiratory protection data, and the other information described above(11). The air sample-stay time approach must rely on models of the respiratory tract as well measurements. This approach stretches inference to its limits, especially for high specific activity alpha emitters when the number of particles on an air filter representing the putative intake becomes very small(12,13).

Inference of dose from measurements of radon or thoron progeny, or worse yet, radon or thoron gas, can be fraught with very significant uncertainty when knowledge of the particle size, equilibrium factor, unattached fraction is added to other uncertainties listed above. This problem becomes severe when there are disconnects between the doses inferred from models and the biological effects that are ascribed to those doses(12-15). The typical solution for this problem is to abandon some aspects of calculations altogether(16) and resort to a 'dose conversion convention'(17,18).

DOSWAGGERY

Unfortunately, it is sometimes necessary to produce values for dose when even less information is available than described above, such as in the case of dosimetry for radiation litigation. In the absence of data, calculations can be based on unsubstantiated assumptions. In the USA, the common, humorous slang term among technical people for a 'wild assumption guess', is a *wag*. When the unsubstantiated assumption is used as input to a scientifically valid formula, the result is a 'scientific wild assumption guess', or *swag*. When the uncertainties in the assumptions dwarf even the uncertainties in the inferential steps, much less the uncertainties in measurements (if there are any), inferring absorbed dose and related quantities following putative intakes of radioactive materials might more properly be called *doswaggery* rather than *dosinference* or *dosimetry*. The term doswaggery is a blend of *dose* and

---

* Two important exceptions to the uncertainties in inferential steps for dose inference following intakes should be noted: ^{3}H and the alkali metals such as ^{137}Cs. For tritium, the dose rate to urine is fairly easily and accurately inferred, and, to first approximation, is assumed to be the dose rate to the person excreting the urine at the time of excretion. For the alkali metals, the relative uniformity of irradiation due to the uniformity of the distribution of the cations in the body makes dose inference from repeated *in vivo* measurements fairly straightforward.

swag with a suffix to make it sound like an action. Doswaggery results in a doswag, or dose of scientific wild assumption guess. Dosewaggery may not rely on measurements at all, or may rely on measurements only tenuously associated with the individual for whom the dose in being inferred. Of course, this is not to imply that dosimetrists themselves should ever be referred to as *wags*.

Often in applied radiation protection it becomes necessary to impute a dose when one is missing, such as in the case of a lost or damaged dosemeter, a spoiled bioassay sample or air sample. Imputed doses* are commonly provided for lost or damaged external dosemeters by interviewing the worker in question along with his or her colleagues and then averaging the preceding and subsequent dosemeter results. By analysing historical data and randomly removing results, the averaging procedure has been shown to be bias free if not particularly accurate(20,21). Such imputation is probably one of the least egregious forms of doswaggery. For job categories in a production line setting, such as nuclear fuel fabrication or work in a radiology department with a constant caseload, perhaps it is justifiably called dosinference. An example of doswaggery in epidemiological studies of uranium miners is the process of assigning doses based on measurements in similar mines when no monitoring information was available for the mine in which a particular miner had worked.

The entire field of dose reconstruction for radiation litigation purposes can become nothing more than doswaggery when, for example, technical personnel are required to infer doses to workers in the uranium mining, milling, and refining industries in the first part of the 20th century in the absence of any concurrent workplace measurements. Projecting distant future doses to a particular individual may also be merely doswaggery, especially for older individuals when much of the dose may be received after the person is deceased. And, as the ICRP(22) has pointed out, there are significant difficulties associated with the use of extended ranges of time and dose when projecting doses to future populations.

CONCLUSIONS

The process of inferring radiation absorbed dose and related quantities to tissues and organs of individuals from measurements, models (physiological, biokinetic, pathway, etc.), and assumptions (effectiveness of respiratory protection, particle size distribution, time of intake) has sometimes been referred to as *dosimetry*. However, not all dose inferences are created equal, and a case has been made for using one of three different terms depending on whether uncertainties in measurement, inferential processes of models and their parameters, or assumptions dominate the uncertainty, and the general range of the uncertainties. Table 1 shows a suggested classification scheme for use of the terms dosimetry, dosinference, and doswaggery.

Table 1. Terminology for different qualities of inferred doses based on range of uncertainty and concomitant contributors to that uncertainty.

Term	Typical dominant uncertainty				
	Measure-ments	Models	Model parameters	Imputed data	Ratio of 97.5%ile To 2.5%ile of inferred dose
Dosimetry	✔ ✔	✔	Relatively trivial	Relatively trivial	1.01 to 2
Dosinference	✔	✔ ✔	✔ ✔	Relatively trivial	2 to 20
Doswaggery	Relatively trivial	✔	✔	✔ ✔	>20

✔ denotes important; ✔ ✔ denotes very important.

*Reissland(19) termed these notional doses, but the term imputed doses is now widely used.

REFERENCES

1. Strom, D. J. and Watson, C. R. *On Being Understood: Clarity and Jargon in Radiation Protection*. Health Phys. **82**(3), 373-386 (2002).
2. International Commission on Radiological Protection. *Report of the Task Group on Reference Man*. ICRP Publication 23 (Oxford: Pergamon Press) (1975).
3. National Council on Radiation Protection and Measurements. *Evaluating the Reliability of Biokinetic and Dosimetric Models and Parameters Used to Assess Individual Doses for Risk Assessment Purposes*. NCRP Commentary No. 15 (Bethesda, MD: NCRP Publications) (1998).
4. Traub, R. J. and Robinson, A. V. *The Sources of Uncertainties Associated with Internal Dose Calculations*. PNL-SA-13686 (Richland, WA: Pacific Northwest Laboratory) (1986).
5. Harrison, J. D., Leggett, R. W., Nosske, D., Paquet, F., Phipps, D. M., Taylor, D. M. and Metivier, H. *Reliability of the ICRP's Dose Coefficients for Members of the Public, II. Uncertainties in the Absorption of Ingested Radionuclides and the Effect on Dose Estimates*. Radiat. Prot. Dosim. **95**(4), 295-308 (2001).
6. Leggett, R. W. *Reliability of the ICRP's Dose Coefficients for Members of the Public. I. Sources of Uncertainty in the Biokinetic Models*. Radiat. Prot. Dosim. **95**(3), 199-213 (2001).
7. Gibson, J. A. B., Birchall, A., Bull, R. K., Henrichs, K., Iranzo, E., Lord, D. J., Piechowski, J., Sollett, E., Tancock, N. P., and Wernli, C. *A European Intercomparison of Methods Used for the Assessment of Intakes of Internally Deposited Radionuclides*. Radiat. Prot. Dosim. **40**(4), 245-257 (1992).
8. Hui, T. E., Loesch, R. M., Raddatz, C., Fisher, D. R. and McDonald, J. C. *An Internal Dosimetry Intercomparison Study*. Health Phys. **67**(2), 217-225 (1994).
9. Hui, T. E., Loesch, R. M. and McDonald, J. C. *The Second Internal Dosimetry Intercomparison Study of the U.S. Department of Energy*. Radiat. Prot. Dosim. **72**(2), 131-138 (1998).
10. Werner, E., Hansen, Ch., Roth, P., Andrasi, A., Beleznay, E., Steger, F., Lovranich, E. and Hochmann, R. *Intercomparison Measurements of Incorporated Radionuclides in Man by Four Whole-body Counters*. Radiat. Prot. Dosim. **58**(4), 277-281, (1995).
11. Strom, D. J., Stansbury, P. S., Selby, J. M., Brake, R. J. and Hall, R.M. *DOE Standard, Internal Dosimetry*. U.S. Department of Energy (DOE*)*. DOE-STD-1121-98 (Washington, DC: U.S. Department of Energy) (1999).
12. Scott, B. R. and Fencl, A. F. *Variability in PuO_2 Intake by Inhalation: Implications for Worker Protection at the U.S. Department of Energy*. Radiat. Prot. Dosim. **83**(3), 221-232 (1999).
13. Birchall, A., James, A. C. and Muirhead, C. R. *Adequacy of Personal Air Samplers for Monitoring Plutonium Intakes*. Radiat. Prot. Dosim. **37**(3), 179-188 (1991).
14. James, A. C. and Birchall, A. *New ICRP Lung Dosimetry and its Risk Implications for Alpha Emitters*. Radiat. Prot. Dosim. **60**(4), 321-326 (1995).
15. Birchall, A. and James, A. C. *Uncertainty Analysis of the Effective Dose per Unit Exposure from Radon Progeny and Implications for ICRP Risk-weighting Factors*. Radiat. Prot. Dosim. **53**(1-4), 133-140 (1994).
16. International Commission on Radiological Protection. *Protection Against Radon-222 at Home and at Work*. ICRP Publication No. 65, Ann. ICRP **23**(2) (Oxford: Pergamon Press) (1993).
17. International Atomic Energy Agency. *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources*. Safety Series No.115 (Vienna: International Atomic Energy Agency) (1996).
18. Strom, D. J. and 17 others. *Occupational Exposure to Radon and Thoron*. White paper for Radiological Control Coordinating Committee (Albuquerque, NM: U.S. Department of Energy, Albuquerque Operations) (1996).
19. Reissland, J. A. *Epidemiological Methods of Assessing Risks from Low Level Occupational Exposure to Ionizing Radiation*. Radiat. Prot. Dosim. **2**, 199-207 (1982).
20. Strom, D. J. *A Strategy For Assessing Occupational Radiation Monitoring Data from Many Facilities for use In Epidemiologic Studies*. Doctoral dissertation, University of North Carolina at Chapel Hill (1984).
21. Watson, J. E., Jr., Wood, J. L., Tankersley, W. G. and West, C. M. *Estimation of Radiation Doses for Workers Without Monitoring Data for Retrospective Epidemiologic Studies*. Health Phys. **67**(4), 402-405 (1994).
22. International Commission on Radiological Protection. *Radiological Protection Policy for the Disposal of Radioactive Waste*. ICRP Publication No. 77, Ann. ICRP **27**(Supplement) (Oxford: Pergamon Press) (1997).

D. J. Strom
Environmental Technology Directorate
Pacific Northwest National Laboratory
Richland, Washington USA. daniel.j.strom@pnl.gov