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:U TITLE: Health physics (New York, N.Y.)
:TITLE: Health physics : official journal of the Health Physics Society.
:IMPRINT: New York : Pergamon Press, c1958-
:ARTICLE: Strom, Daniel: FORUM - On Being Understood: Clarity and Jargon in Radiation Protection
:VOL: 82 :NO: 3 :DATE: 2002 :PAGES: 373
:VERIFIED: <TN:61207>OCLC ISSN: 0017-9078 [Format: Serial]
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Forum

ON BEING UNDERSTOOD: CLARITY AND JARGON IN RADIATION PROTECTION

Daniel J. Strom and Charles R. Watson*

***Abstract*—While much of the language used to express the concepts of radiation protection works effectively, there are many ill-chosen names and phrases and much jargon that permeate our professional speech and writing. From the oxymoron "internal exposure" to the "snarl word" "decay," there is much room for improvement. This essay identifies many of the problems and suggests solutions. We examine the kinds of confusions that can result from using familiar words with unfamiliar meanings and the need for neology. We offer insights into specific and unambiguous naming of physical quantities and explore the seemingly unlimited kinds of "dose." We disaggregate exposure from irradiation following intakes, and unmask units like "gram rad per microcurie hour." We call for a definition of radiation weighting factor that doesn't result in a violation of the law of conservation of energy. We examine the subtleties of distinguishing between radiation and radioactive materials. Some words, such as "exposure," have multiple meanings, while at other times there are different words or phrases with the same meaning, such as "critical level" and "decision level" or "detection level" and "minimum detectable amount." Sometimes phrases are used whose meaning is unclear or not agreed upon, such as "lower limit of detection." Sometimes there are words that are simply not apt, such as "disintegration" applied to the emission of a subatomic particle from a nucleus.**
Health Phys. 82(3):373–386; 2002

Key words: education, health physics; public information; journal content; quality assurance

INTRODUCTION

THIS ESSAY concerns the vocabulary of radiological science, and thus radiation protection—fields that are barely 100 years old. The vocabulary of radiological science has developed in a variety of cultures and in a variety of languages. Like most sciences and professions, it has developed in response to changing conditions, states of knowledge, and societal needs and values, without any central direction. Many commonplace terms have come into use without much reflection or have persisted unchanged by those who reflect. Many of its concepts were named by people whose primary skills were technical, not linguistic. Some concepts arose in secret and in parallel in different countries and different languages. Many concepts have undergone significant evolution over time. The product of this evolution, at least in English language and particularly its American variant, is an amazing mess of jargon and ill-named concepts that derive from important and innovative technological thinking by many intelligent people. The result of this jargon is that non-specialists are often confused and befuddled by our pronouncements.

Too often in communicating information about radiation and radioactive materials, we encounter difficulties in conveying some of the most fundamental concepts, such as the distinction between *radiation* and *contamination*. These difficulties are caused in part by fuzzy thinking due to the imprecise or inappropriate use of language in our profession. We even have institutionalized confusion, such as the definition of the quality factor and radiation weighting factor.

In this essay we examine some of our terminology, reflect on it, and suggest some pitfalls to be aware of and a few changes in practice. In particular, we suggest that some creative neology is in order (Strom 1996, 1997). To understand this need, we explore some of the origins of new words such as acronyms and blends, and the notions of extensive and intensive quantities and the neologisms in metrology. We also examine the enduring problem of the confusion of radiation and radioactive materials.

THE ULTIMATE SOURCE

The ultimate source for metric practice is the Conseil Général de Poids et Mesures (CGPM) through the Bureau International des Poids et Mesures (BIPM 1991). In the U.S., the U.S. Department of Commerce has the lead, with documentation provided free and online by the National Institute for Standards and Technology (NIST) (NIST 1995; Taylor 1995). Full on-line versions of the NIST documents are available at http://physics.nist.gov/SI. For specific matters regarding radiological units, the last word comes from the International Commission on Radiological Units and Measurements (ICRU 1993, 1998).

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(*Manuscript received* 11 *October* 1999; *revised manuscript received* 14 *April* 2001, *accepted* 27 *June* 2001)

0017-9078/02/0

Units have full spelled-out *names* and *unit symbols* (not abbreviations). Authors should take particular note of Appendix B in Taylor (1995).

Units have regular plurals (Strom et al. 1982; ASTM 1993; Taylor 1995), but unit symbols remain invariant in the plural. It is correct to state that equivalent dose is measured in units of sieverts (not "units of sievert"), and temperatures are measured in kelvins. Since there are no unit symbols for rad and rem, they are always "written in full" and take regular plurals (e.g., 5 rems not 5 rem). If you are in doubt, substitute "foot" or "feet" or "mile" or "miles" and choose the plural spelling if it sounds right.

It is curious that reps, rads, and rems, with normal plurals, appeared widely in publications in the 1950's by the ICRP (1955), Herbert Parker (who invented the terms "rep" and "rem;" see, e.g., several papers in Kathren et al. 1986), and Lapp and Andrews (1963), but that many later used them as invariant in the plural.

An excellent brief reference on metric practice, ideal for students and those seeking a refresher, appears annually in the August issue of *Physics Today* (Nelson 1999).

ABBREVIATIONS, ACRONYMS, BLENDS, CLIPPINGS, CODES, INITIALISMS, AND SYMBOLS

An abbreviation is a general term referring to the shortening of a word or phrase, which may or may not have a period (e.g., mi., Dr., Penna. or Wash.). Abbreviations include more specific shortening types such as initialisms, acronyms, symbols, codes, clippings, and blends. An initialism is simple a collection of initials (e.g., NRC, NCRP). An acronym is a pronounceable abbreviation (e.g., RadCon) that may be an initialism (e.g., ALARA); some acronyms simply become words through usage (e.g., laser, radar, rad, rem). Unit symbols for the international metric system (SI), such as W for watt and Bq for becquerel, are specified by the Conseil Général de Poids et Mesures (BIPM 1991). Other symbols include Greek letters (α, β, μ) and $, ¶, and §. Following standard typesetting conventions, algebraic symbols that stand for quantities or variables are italicized, both in text and in equations. A *code* is a symbol specified by some organization (e.g., 2-letter U.S. Postal Codes for states such as AK and WY; 3-letter ISO country codes such as USA and JPN). A clipping is a shortened form, e.g., ad for advertisement, rad worker for radiological worker. A blend is a combination of two words, e.g., brunch.

EXTENSIVE AND INTENSIVE QUANTITIES

An extensive quantity depends on the size or extent of the object it refers to: the larger the object, the larger the quantity (all other things being equal). For example, mass (kg) is an extensive quantity.

An intensive quantity is independent of the size or extent of the object. Intensive quantities are always expressed in "per something else" when in base SI units: per mole, per meter, per square meter, per cubic meter, per kilogram, etc. Intensive quantities like exposure and absorbed dose may have special units that contain implicitly the "per." For example, density (kg m^{-3}) is an intensive quantity. Incidentally, while this journal prohibits the use of the solidus ("/") in expression of units, single use of the solidus is allowed in the international metric system (Taylor 1995).

Recent international guidance (ISO 1992; Taylor 1995; McGlashan 1995) for intensive quantities suggests five new adjectives, as shown in Table 1. These are lineic (from line), areic (from area), volumic (from volume), massic (from mass), and mentic (from mole). For example, using massic avoids the uncertainty of what the word "specific" means in phrases like specific heat (massic heat capacity) and specific gravity (a ratio of two densities).

Important intensive and extensive quantities as currently defined are shown in Table 2, with new and precise names for the intensive quantities suggested in parentheses. Also included in Table 2 are several quantities of interest in radiation protection.

Some intensive quantities depend on the state of compression of a material, that is, its density (volumic mass), while others are independent of density. Shown in Table 3 are three important examples, including attenuation coefficients, stopping powers, and shield or absorber thickness.

THE NEED FOR NEOLOGY

Neology is "the use of a new word or expression or of an established word in a new or different sense; the use

Table 1. Adjectives for intensive quantities (ISO 1992; Taylor 1995; mentic from McGlashan 1995).

Qualifier: per unit	Root word	Usage: ISO, NIST	Usage: Current USA	Example
length	line	lineic	linear. . . density	lineic charge, C m^{-1}
area	area	areic	surface. . . density areal. . . density	areic activity, Bq m^{-2} (e.g., surface contamination)
volume	volume	volumic	. . .density, . . .concentration	volumic mass, mg m^{-3} (e.g., an aerosol)
mass	mass	massic	specific. . ., mass concentration	massic energy, J kg^{-1} (absorbed dose, chemical energy in a battery)
amount of substance	ment	mentic	per mole	mentic mass, g mol^{-1}

Table 2. Extensive and analogous intensive quantities, with special reference to radiological quantities.

Extensive quantity	Unit	Intensive quantity	Unit
Number	none, mol	Number density (volumic number)	m^{-3}
Length	m	—	
Area	m^2	—	
Volume	m^3	—	
Mass	g, kg	Atomic mass (mentic mass)	g mol^{-1}
	g, kg	Density (volumic mass)	kg m^{-3}
	g	Mass per unit area (density-thickness or areic mass)	g cm^{-2}
Force	N	Pressure (areic force)	N m^{-2}, Pa
Heat (Energy)	J	Temperature (not strictly analogous)	K
	J	Specific heat	J kg^{-1} K^{-1}
Energy [imparted]	J	Absorbed dose (massic energy)	J kg^{-1}, Gy
	keV	Linear energy transfer (lineic energy)	keV μm^{-1}
Charge	C	Exposure (massic charge)	C kg^{-1}
Activity	Bq	Specific activity (massic activity)	Bq kg^{-1}
		Contamination (areic activity)	Bq $(100\ cm^2)^{-1}$
		Concentration (volumic activity)	Bq m^{-3}

Table 3. Analogous density-dependent and density-independent quantities.

Density-dependent quantity	Unit	Density-independent quantity	Unit
Linear attenuation coefficient	m^{-1}	Mass attenuation coefficient	m^2 kg^{-1}
Linear stopping power	J m^{-1} keV μm^{-1}	Mass stopping power	J m^2 kg^{-1} MeV cm^2 g^{-1}
Thickness (for a given absorption)	m	Density-thickness	kg m^{-2}

of new expressions that are not sanctioned by conventional standard usage; the introduction of such expressions into a language" (Gove 1961). A neologism is "a new word, usage, or expression" (Gove 1961). The English language is very powerful because of its ability to adopt words from other languages, its ability to add new meanings to words, and its ability to accept new words. Neology is an integral part of English.

Successful examples of neologisms include laser and radar, words whose origins were initialisms,† but which have been simply adopted by English speakers as words. The Internet (itself a neologism) is replete with neologisms, including many of the best kind, the self-defining neologisms, such as netiquette and vaporware.

In our field, we have the pronounceable, if somewhat dated, initialisms "rep," "rad," and "rem" for units, and the neologisms "kerma" and "cema" for quantities.‡ Other neologisms that have appeared in the last 100 years include most of the common units of radiological science and radiation protection, including roentgen, curie, becquerel, gray, and sievert. Some suggested neologisms that never caught on are a unit called the "failla" [after Gioacchino Failla; 10^{-6} lifetime fatality risk, introduced by the National Council on Radiation Protection and Measurements (NCRP) in a draft report in the early 1980's but never adopted; also called a "micromort" by some] and the term "effectance" [floated in 1989 and 1990 by the International Commission on Radiological Protection (ICRP) to replace effective dose equivalent].

When defining new concepts, it is our position that new-word neology (as opposed to new meaning for old words) is sometimes needed to be specific and precise when defining new concepts. New words have been coined for units, but, unfortunately, not for most concepts. Several examples of problems created by *not* neologizing are given, as well as a few suggested neologisms to fill gaps.

Fisher (2000) reported a successful neology: the word "decorporation."

KAPLAN'S THEOREMS OF PROBLEMS AS A CALL FOR CLARITY

Stanley Kaplan, a pioneer in probabilistic risk analysis and modern applications of Bayesian statistical methods, has two "theorems" posted on his wall (Kaplan 1997):

- Theorem 1. 50% of the problems in the world result from people using the same words with different meanings.
- Theorem 2. The other 50% of the problems in the world result from people using different words with the same meanings.

Kaplan claims that when an argument between two individuals begins in his office, he listens, identifies which theorem applies, and which words or meanings are

† laser: "light amplification by the stimulated emission of radiation;" radar: "radio detection and ranging."

‡ rep, roentgen equivalent physical; rad, radiation absorbed dose; rem, originally roentgen equivalent mammal and later roentgen equivalent man; kerma, kinetic energy released in matter (not strictly speaking an intitialism since it uses two letters from the last word); cema is not an initialism but a term for the analog of kerma released by *charged (whence the c) as opposed to uncharged* particles.

involved, and simply states what's happening. He said that the heat usually disappears, and information exchange begins again (Kaplan 1997).

We have seen Kaplan's theorems describe many communication problems associated with radiation protection and radiological sciences. We're tempted to add a third theorem:

- Theorem 3. There are a significant number of problems in the world caused by people using words with no idea what they mean.

Much media reporting of matters radiological can be described by Theorem 3, and it is usually difficult to figure out whether Theorem 1 or Theorem 2 also applies.

As serious as the non-specialist problems are, complaining about them here will do little good. However, there is hope that we in the radiation protection world can learn to be more precise in our use of language and at least uphold our responsibility for clear, unambiguous communication.

CASE STUDY: SOURCES, EXPOSURES, INTAKES AND "ONTAKES," AND IRRADIATION

It is important to disaggregate several concepts that are often lumped together, examining along the way, why we have come to use words the way we have. By separating source, exposure, intake or "ontake" (our neologism for material contacting skin) of the source, and irradiation, we illustrate why phrases like "internal exposure" should be abandoned in favor of clearer terminology that communicates to non-experts and scientists outside of health physics (Strom 1996).

As shown in Fig. 1 and outlined in Fig. 2, four sources are identified: airborne, food- and drink-borne, and surface- and liquid-borne radioactive materials, and penetrating radiation sources (machines and radioactive materials) that remain at a distance from the body.

Five kinds of exposures are identified: person encounters contaminated air; person consumes contaminated food or drink; person's skin is penetrated by contaminated material; person's skin contacts contamination or contaminated surface; and person comes in proximity to source of penetrating radiation.

The processes of intake and ontake of the sources are distinct from the exposures, that is, the encountering of contaminated air or surfaces. "Ontake" can also mean "the *amount* of radioactive material that got on the skin," the way intake can refer to "the *amount* of radioactive material that was taken into the body." Context serves to distinguish the process from the amount in each case.

Finally, the time course and process of irradiation in each case is described. The fact that exposure and irradiation are simultaneous for external sources has muddied the essential distinction between these concepts for materials that get on or in the body and only then begin to irradiate a person.

NON-TECHNICAL DEFINITIONS: EXPOSE AND EXPOSURE

The word *expose* is a transitive verb with several related meanings, two of which are confused in health physics. One meaning of expose is *to submit, subject or allow to be subjected to an action or an influence;* for example, to expose people to fine arts, to expose someone to a disease, to expose a worker to dust. Another distinct and specific meaning is *to subject something (e.g., photographic film) to the action of radiant energy or light.*

The word *exposure* is a noun meaning *the act, condition, or instance of being exposed*; this is a *cause*. A related meaning of exposure is *the amount or quantity of the agent to which something is exposed,* such as the amount of light reaching film; this is an *effect*. Using the same word for a cause and an effect leads to problems, as stated in Kaplan's Theorem 1.

TECHNICAL DEFINITIONS OF EXPOSURE IN RADIOLOGICAL SCIENCE

Exposure has taken two additional special meanings in radiological science. The first special meaning of exposure is the quantity of charge liberated per unit mass in air by photons between the energies of 10 keV and 3 MeV. In this sense, "exposure is the ionization equivalent of collision kerma in air" (Attix 1981).

The second special meaning of exposure is the product of potential alpha energy concentration *(PAEC)* and time, expressed in J h m^{-3} or working level months (WLM), or the product of volumic activity (airborne concentration) of radioactive material (Bq m^{-3}) and exposure time (h). The latter product is often normalized by dividing the airborne concentration by the derived air concentration (*DAC*, that volumic activity, which, breathed at 1.2 m^3 h^{-1} for 2,000 h, produces an intake that results in 50 mSv committed effective dose or 500 mSv committed equivalent dose to Reference Man) for that radionuclide. This innovative normalization results in units of "*DAC* h" and permits one to sum exposures to different radionuclides for comparison to a limit.

"INTERNAL EXPOSURE:" A PHRASE WE MUST BANISH

The phrase "internal exposure" has been used in the U.S. for decades, and has appeared in some official government documents (e.g., U.S. Department of Energy 1994). Users of this phrase may not be exactly sure what they are referring to, except that there is or has been the possibility that a person may have an intake of radioactive materials. The phrase may refer to exposure in the sense of coming into harm's way, it may refer to the intake of material, or it may refer to the irradiation of the person that takes place after the intake. The phrase is imprecise and confusing because

- All sources of radiation start *external* to body;

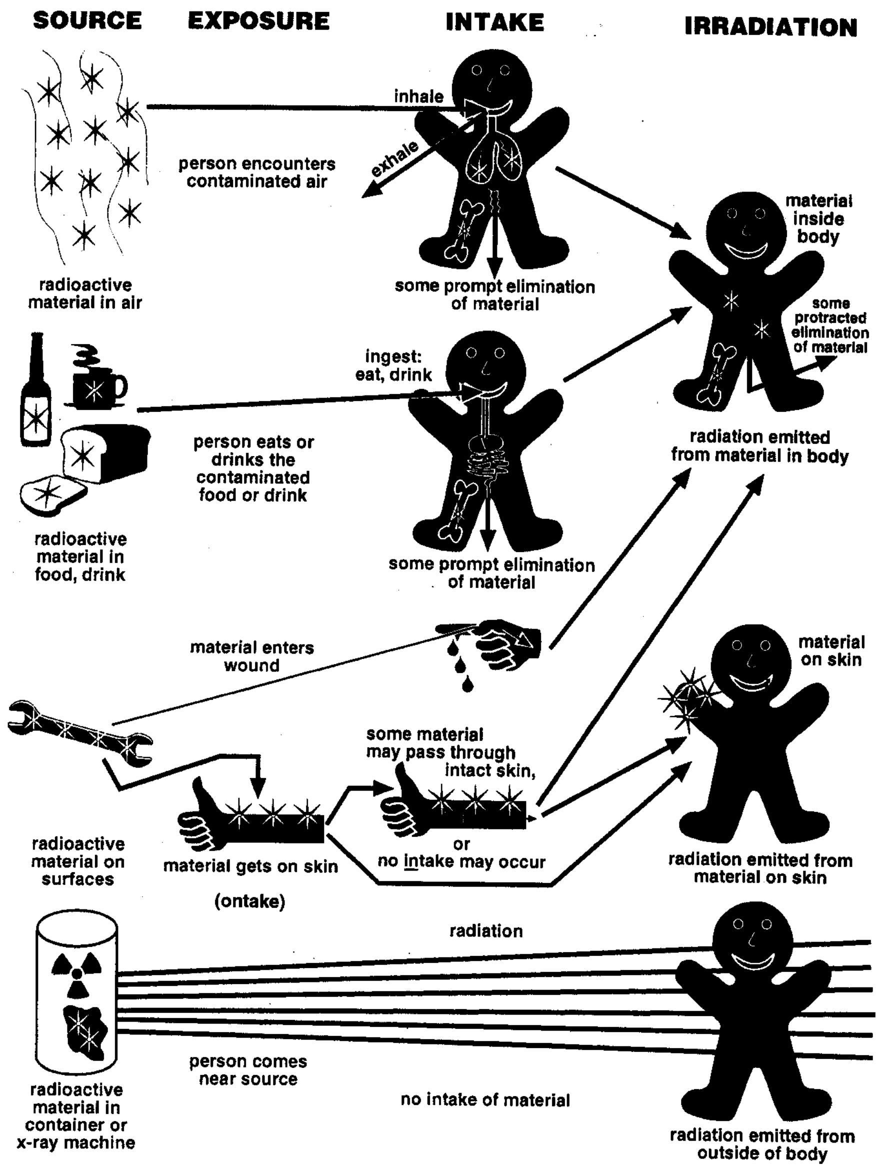

Fig. 1. An illustration of the distinction between "exposure" to radioactive material (a cause) and the subsequent, perhaps protracted, "exposure" to radiation emitted by that material while some of it is retained in and/or on the body (an effect). Communication clarity is enhanced if the latter "exposure" is called "irradiation."

- All irradiated organs are *internal* to the body; and
- To a lay person, exposure means uncovering, being exposed to an agent (microbe, chemical, radionuclide, energy field) outside the body.
  Table 4 shows the location of radiation sources and irradiation, as well as the timing of exposure and irradiation for external sources, ontakes, and intakes.
- Besides causing Kaplan's First Theorem communication problems, the phrase "internal exposure" is an oxymoron. It is our experience that the phrase confuses workers, educated lay persons, physicians, toxicologists, and industrial hygienists.
- "Exposure" has been used for both a cause (coming into harm's way) and its effect (irradiation) (OECD 1992), a confusing situation. Communication is enhanced if we distinguish between exposure and irradiation, as shown in Fig. 1. Being near radioactive materials or radiation generating machines that emit penetrating radiation may result in *irradiation by an external source*. Exposure to the source and irradiation by the source are simultaneous. There is no intake of material. Irradiation ceases when exposure ceases. Exposure to air-, food-, drink-, and surface-borne radioactive materials may result in intake or ontake of material, with subsequent *irradiation by a topical source* or *irradiation by an internal source* or both. Exposure to the material and the irradiation by the material occur at different places and different times.

Source	Exposure	Intake or Ontake	Irradiation and Fate of Source	
1. Airborne radioactive material (radioactive gas or aerosol)	1. Person encounters contaminated air	1. Intake by inhalation: airborne radioactive material enters respiratory tract (R tract)	**Irradiation by Internal Source** 1, 2, 3a & 3b. • Material emits radiation from within body • Source stays with person for some period of time • Material irradiates "while passing through" • Some or all material eliminated from body by decay and/or by natural or enhanced decorporation	1. Material irradiates lung tissue and body from R tract • Some material may be absorbed systemically from R tract; • Some material may translocate to GI tract; see 2 below.
2. Food-borne radioactive material: Radioactive material in or on food, drink, cigarette, gum, cosmetics, etc.	2. Person eats or drinks contaminated food or beverage, or has oral contact with other contaminated items	2. Intake by ingestion: radioactive material enters the gastrointestinal tract (GI tract)		2. Material irradiates GI tissue and body from GI tract • Insoluble material passes through (essentially remains "outside" of the body, in the contents of the GI tract) • Some material may be absorbed systemically from GI tract
3. Surface-borne radioactive material: Radioactive material on surfaces, in environment	3a. Person's skin broken by contaminated surface or object	3a. Intake by entry through wound or injection		3a. Material irradiates body from wound site • Some material may be absorbed systemically from wound site • Some material may translocate via lymphatic system • Some material may remain at wound site indefinitely
	3b & 3c. Person comes in contact with contamination or contaminated surface	3b. Ontake followed by intake: partial or total absorption of material in contact with skin through intact skin		3b. Some material may be absorbed systemically from skin
			Irradiation by Topical Source 3b & 3c. • Material emits radiation while in contact with skin • Source stays with person for some period of time • Material removed by decay and/or sloughing	3b & 3c. Topical material irradiates nearby tissues preferentially due to range and inverse square law effects.
		3c. Ontake *not* followed by intake: material remains on skin, in contact		
4. Radiation-generating device or radioactive material that remains outside of the body	4. Person comes near a source of penetrating radiation	4. No intake or ontake of source itself	**Irradiation by External Source** 4. Machine or material remains outside of body	4. Machine or material emits radiation which penetrates body, irradiating tissues

Fig. 2. Detailed caption for each item and process in Fig. 1.

Table 4. The "where" and "when" of exposure and irradiation.

Condition	External source	"Ontakes" of radioactive material (skin contamination)	Intakes of radioactive material
Irradiation source is outside of body	✓	✓	
Irradiation source is on body (topical)		✓	
Irradiation source is inside of body			✓
Exposure and irradiation	Simultaneous	Sequential (?)	Sequential
Course of irradiation can be altered after exposure		✓	✓

Following ontake or intake, material may remain on or in a person for an extended period of time. In cases of intake or ontake, irradiation usually continues after exposure ceases, and irradiation patterns change over time.

When considering what happens when people encounter radioactive aerosols, careful distinctions are needed between and among the terms

- exposure (encountering radioactive substance);
- intake (and its time course) of material into an intake compartment such as the respiratory tract, gastrointestinal tract, or wound;
- ontake (caused by dermal exposure) of material onto the skin;
- deposition (a process by which particles deposit in the respiratory tract);
- uptake (from intake compartment to systemic compartment);
- translocation of material (moving from one place to another in the body);
- retention of material (temporal and spatial patterns);
- irradiation target organs and tissues by retained quantities of material; and
- elimination (radioactive decay, urinary and fecal excretion, exhalation, sloughing, secretion, etc.).

DISTINGUISHING BETWEEN RADIATION AND RADIOACTIVE MATERIAL OR RADIOACTIVE SUBSTANCE

Some purists will claim that the word "radioactivity" refers to the phenomenon of spontaneous quantum mechanical transitions in atomic nuclei, and that the word should not be used as a synonym for the material or substance having this property. We fear that we have lost the battle on this distinction, and concede that radioactivity will continue to be used for both substance and phenomenon.

Why is it that there is so much nonsense spoken and written about radiation and radioactivity? One of us (Strom) has a file titled "Lies, Nonsense, Nukespeak and Propaganda" full of clippings from the popular press containing gems like "a curie is the amount of radiation in a pound of uranium." We contend that *most* of what one reads, sees, and hears in the media is wrong from a technical point of view.

To help people understand why we cringe when a reporter states, "the nuclear plant released radiation," we devised Figs. 3, 4, and 5. These three figures summarize properties of the categories "radiation" and "radioactive material." We have limited the figures to radiation emitted from radioactive materials, nuclear devices, or "ordinary" ionizing radiation-producing machines and omitted exotic, high-energy accelerators, or high-atomic number, high-energy (HZE) galactic radiation.

Fig. 3 includes properties that apply to both radiation and radioactive materials. They are grouped by whether they apply fully, partially, or not at all.

Fig. 4 includes nine properties that have different meanings for radiation than they have for radioactivity, and these lead to Kaplan's Theorem 1 kind of communication difficulties. The first eight properties (absorb, deposit, filter, emit, leak, pass through the body, penetrate intact skin, and have a particle nature) are particularly tough to sort out for a non-specialist. We legitimately speak of radiation leaks from an x-ray tube housing, and of radioactive material leaks from a pipe or a sealed source; the meaning of the word leaks, in terms of the physical process, is vastly different in the two cases. An intact tube housing is penetrated to some extent by x rays. Such leakage is normal, known, and accounted for by the designer. On the other hand, a leak of radioactive material is often an abnormal, unplanned occurrence resulting in fugitive material being where it isn't intended to be. The reader is invited to consider what each of these properties means in the context of ionizing radiation and in the context of radioactive material.

Property 29 is especially subtle. All of the radiations listed, if sufficiently energetic, as well as the radiations from some radioactive materials, can create radioactive materials from nonradioactive materials through a variety of *nuclear* interactions. However, a non-specialist, on

Property	Radiation					Radioactive Material *(Contamination)*
	α	β	γ, x	neutron *fast*	neutron *thermal*	
1. Existed in significant quantities in prehistoric times 2. Can be natural	●	●	●	●	●	●
3. Is mentioned in the *Talmud, Bible* or *Koran* 4. Is discussed by Aristotle, Copernicus or Galileo 5. Is discussed by Newton, LaPlace or Darwin	○	○	○	○	○	○
6. Is discussed by Bohr, Einstein and Fermi 7. Can be created by humankind 8. Can be contained 9. Can be used safely 10. Can cause adverse health effects 11. Is used for medical diagnosis and therapy 12. Can be produced in a nuclear reactor or nuclear weapon 13. Can be contained	●	●	●	●	●	●
14. Can create member of other category	◗	◗	◗	●	●	●
15. Can be released	"radiation release" not normally used by scientists					●
16. Can emit "rays" 17. Has a half-life 18. Decays (in the sense of "diminishes")	○	○	○	●	●	●
19. Has significant kinetic energy	●	●	●	●	○	○ (exception: DU bullet)
20. Has mass	●	●	○	●	●	●

Fig. 3. Properties with common meanings for radiation and radioactive materials. Key: ● means that the particle or material at the top of this column has this property; ◗ means that it can have, sometimes has, or partially has this property; ○ means that it does not have this property.

Property	Radiation					Radioactive Material ("Contam-ination")
				neutron		
	α	β	γ, x	*fast*	*thermal*	
21. Can be absorbed 22. Can deposit energy in the body 23. Can be filtered 24. Can be emitted 25. Can leak	●	●	●	●	●	●
26. Can pass through the body	○	●	●	●	●	●
27. Can penetrate intact skin	○	◗	●	●	●	◗
28. Is a particle	●	●	◗	●	●	◗
29. Can create radioactive material from nonradioactive material	◗	◗	◗	●	●	●

Fig. 4. Properties with different meanings for radiation and radioactive materials. Key: ● means that the particle or material at the top of this column has this property; ◗ means that it can have, sometimes has, or partially has this property; ○ means that it does not have this property.

Property	Radiation					Radioactive Material ("Contam-ination")
				neutron		
	α	β	γ, x	*fast*	*thermal*	
30. Can be eaten, drunk, or inhaled 31. Can be deposited in the lung 32. Can concentrate in an organ 33. Can be excreted 34. Can be washed off skin 35. Can be biologically concentrated in environment 36. Can contaminate air or water 37. Can be concentrated 38. Can emit the other one 39. Persists over time 40. Can be stored passively 41. Is a substance 42. Is a chemical 43. Can be a gas, liquid, or solid 44. Can be "fallout" from nuclear weapon or accident	○	○	○	○	○	●
45. Can be removed from the body	○	○	○	○	○	◗
46. Is a wave	◗	◗	◗	◗	◗	○
47. Is a "ray"	●	●	●	●	●	○
48. Is produced in an ordinary x-ray machine	○	○	●	○	○	○
49. Is pure energy	○	○	●	○	○	○
50. Can annihilate in ordinary matter	○	◗	○	○	○	○

Fig. 5. Properties that uniquely distinguish between radiation or radioactive materials. Key: ● means that the particle or material at the top of this column has this property; ◗ means that it can have, sometimes has, or partially has this property; ○ means that it does not have this property.

hearing that a liter of radioactive waste had leaked into a 1,000-L tank of pure water, would say that 1,000 L of radioactive material had been "created" from 1-L of radioactive material. The specialist would not see creation of radioactive material, but dilution of radioactive material.

Fig. 5 includes properties that uniquely distinguish between radiation and radioactive materials. Properties 30 through 45 are sensible only for material, not radiation. Note that property 31, "can be deposited in the lung" is taken to be distinct from property 22 in Fig. 4, "can deposit energy in the body." One can split hairs and state that an alpha particle having only thermal energy can be physically deposited in the body, but this is not a consequential event in the same sense as having strontium deposit in forming teeth in a child. Property 45, "can be removed from the body," is a key idea for distinguishing radiation and radioactive materials: once a particle of radiation deposits its energy in the body, a virtually instantaneous event on a human time scale, the radiation ceases to exist as radiation and therefore cannot be removed from the body. On the other hand, radioactive material, if its half-life is sufficiently long, can be.

Figs. 3, 4, and 5 are sufficiently complex that it is no surprise that non-specialists are confused and use the words incorrectly. However, it is important that specialists always be clear in their own minds about the terminology, and be prepared to help an interested non-specialist understand the subtleties of the words.

WHAT IS "DOSE?"

There are many "legitimate" kinds of dose quantities (ICRP 1977, 1991; ICRU 1962, 1971, 1973, 1980, 1993, 1998; Meinhold 1995). As shown in Table 5, there are many named quantities, not to mention "dosage." There have been many articulate complaints about the instability of radiation protection quantities and the problems with dose equivalent and equivalent dose (Greening 1986; Brucer 1987a, 1987b; Rossi 1991; Hoefert 1997; McDonald 1997; Thomas 1997, 1998) and as many responses. There are also prominent authors who do not believe we even have the right quantities (Bond 1991; Bond et al. 1995; Cameron 1992; Feinendegen et al. 1994), but we do not enter that discussion here. In any case, the plethora of names for "dose"-like quantities is staggering.

The ICRP's shift from "effective dose equivalent," defined in Publication 26 (ICRP 1977) but not named until Publication 28 (ICRP 1978), to "effective dose" in its 1990 Recommendations (ICRP 1991) created a nomenclature mess. And changing from dose equivalent to equivalent dose at the same time certainly didn't improve understanding. In 1989 and 1990, the ICRP proposed, then abandoned, the neologism "effectance" for "effective dose." In retrospect, it would have been better for communication to create a new word for the new quantity (effectance, perhaps?), rather than simply rearranging common words that already weren't clear.

One of our favorite insights into the changes in dose equivalent comes from the fact that, in French, the 1950's concept of dose equivalent ("equivalent de dose") is masculine, while equivalent dose ("dose equivalente") is feminine. We knew that the ICRP had made a lot of progress between 1977 and 1990, but a gender-change for its fundamental radiation protection quantity was hidden from readers of the English text.

The U.S. Department of Transportation uses the phrase "radiation level" for dose equivalent rate or equivalent dose rate from a package. Radiation level is far more comprehensible than any of the quantities that specialists use. We advise its use in talking to the public, e.g., "The radiation level near the shipping container was a fraction of natural background."

A DIMENSIONLESS QUALITY FACTOR Q OR RADIATION WEIGHTING FACTOR W_R VIOLATES CONSERVATION OF ENERGY

The ICRU, ICRP, CGPM, and the NIST state that Q and w_R are dimensionless. The statement by the ICRP

Table 5. "Dose" as a scientific literacy problem for amateur health physicists and the average american.[a]

absorbed dose	individual dose equivalent, superficial
acceptable dose	individual dose equivalent, penetrating
accumulated dose (equivalent)	integrated dose equivalent (ICRP 56 p. vii)
air dose	intermediate dose (equivalent)
ambient dose equivalent	lens-of-the-eye dose
annual effective dose equivalent	lethal doses:
cell dose	$LD_{10/60}$
collective dose (equivalent)	$LD_{50/60}$
collective effective dose equivalent	$LD_{90/60}$
committed dose (equivalent)	lethal dose (equivalent)
critical organ dose (equivalent)	lifetime dose (equivalent)
cumulative annual effective dose equivalent	low dose (equivalent)
cytogenetic dose	midline dose
deep dose (equivalent)	minimum detectable dose (equivalent)
depth dose	organ dose (equivalent)
directional dose equivalent	personal dose equivalent
dose equivalent index, deep	prompt dose (equivalent)
dose limit	public dose
dose (equivalent) commitment	r-dose
dose equivalent index, shallow	RBE dose
dose (equivalent)	reference dose
effective dose (equivalent)	relevant dose
entrance dose	residual dose (equivalent)
equivalent dose	shallow dose
estimated dose (equivalent)	skin dose
exit dose	tissue dose (bone dose, . . .)
exposure	tolerable dose
exposure dose	tolerance dose
extremity dose	total (effective) dose (equivalent)
fractionated dose (equivalent)	unacceptable dose
high dose (equivalent)	wasted dose (equivalent)

[a] Partially adapted from Lushbaugh et al. (1990).

and the ICRU that both the gray and the sievert have dimensions of J kg^{-1} results in 20 J kg^{-1} = 1 J kg^{-1} when alpha particles are in question, since 1 Gy = 20 Sv. Merely claiming that Q is a dimensionless weighting factor does not avoid the logical trap of creating energy from nothingness by using a committee-generated multiplying factor. Those who think that Q and w_R are dimensionless should try to explain dose equivalent or equivalent dose to a bright young physics major entering a radiological science graduate program.

Consider the analogous example of liters (L) of fuel and kilometers (km) of distance traveled by an automobile. Suppose we have a standard, reference automobile that travels 10 km L^{-1}, and a new, improved model that travels 20 km L^{-1} of fuel burned. When we perform an experiment by putting 10 L of fuel in each car, the cars travel 100 and 200 km, respectively. The *R*elative *F*uel *E*ffectiveness, *RFE*, for the two cars is 200 ÷ 100 = 2. Clearly, the new, improved car *behaves as if it were the standard reference car with 20 L of fuel*. But in no sense did we have 20 L of fuel in the new, improved car!

Similarly, a biological system irradiated with 0.1 Gy of α radiation may *behave* as if it had been irradiated with 2 Gy of β radiation, but we never had 2 J kg^{-1} in the α experiment; we only had 0.1 J kg^{-1}. We take this difference in *biological* behavior into account through the use of dose equivalent (should it be called dose *behavior*?), calling the 0.1 Gy of α-radiation 2 Sv. In no physical sense is 2 Sv of α-radiation 2 J kg^{-1}.

The ICRP and the ICRU can extricate themselves from the problem by recognizing dose equivalent for what it is: a quantity that bears a special relationship to energy per unit mass through *dimensioned* weighting factors, Q (or w_R), in Sv Gy^{-1}. Other weighting factors, such as w_T are dimensionless, but Q and w_R must have dimensions. The sievert is revealed, not as a physical unit, but as a unit of stochastic risk, or more precisely, a unit of *detriment* as defined by the ICRP (1991).

How did the ICRP and the ICRU fall into this logical trap? Quite simply, Q was originally taken as an average relative biological effectiveness (*RBE*) for various kinds of radiations. *RBE* is a ratio of two doses, and is therefore dimensionless. Q, however, is not a ratio, and can have dimensions; in fact, it must have the dimensions of Sv Gy^{-1} in order for the definitions of dose equivalent and effective dose equivalent not to violate the well-established principle of conservation of energy.

The inclusion of a so-called dimensionless Q in the specific effective energy (*SEE*) values in the ICRP Publications 30 and 61 methods makes the results of those calculations useless for mixed α-β emitters when the Qs or w_Rs change. Keeping the internal dose components separated by radiation type would be a much more valuable service to the user of the ICRP publications. The ICRP should leave Q out of the energy terms weighted by absorption fractions (call them, perhaps, *absorbed energies*) and tabulate them separately.

Variants of these arguments have been presented by many authors (including Strom 1989) over the past several decades (Neufeld 1969; Kellerer 1990), including recently by Thomas (1998). We can only hope that someday they will be heard.

MORE TERMINOLOGY

Table 6 lists jargon terms or phrases we have encountered in radiation protection that are not helpful in communication. Table 6 also gives our preferred alternatives.

"Health physics," the name of this journal, was coined, we are told, during the Manhattan Project to refer to radiation protection activities. Use of the word "radiation" was forbidden, and so in order to fool the enemy, "health physics" was used instead. Unfortunately, we've been fooling our friends ever since. The Health Physics Society has recognized this and taken positive and constructive action to help the name gain recognition.

"Internal dosimetry" is much less specific than "intake dosimetry," which specifically refers to the inference of dose-like quantities from bioassay and other measurements. The word "internal" has been discussed above in the context of "internal exposure."

"Retained quantity" is the ICRP's term for the amount of activity in a body or organ or tissue. It clearly embraces the notion that the amount may change. The older phrase "deposition" used to refer to retained quantity is not apt, and contains the confusion of the processes of deposition of particles in various parts of the respiratory tract, the probabilities of these events as a function of aerosol characteristics, and the notion that radionuclides "deposit" in organs or tissues such as bone and forming teeth. While the latter notion of deposition may be appropriate for radium or strontium in bone and teeth, it is not at all sensible for the many forms of radioactive material that are really "just passing through" the body, such as organic and inorganic tritium and carbon, and the alkali metals such as cesium. The "deposition" of energy by ionizing radiation is also a reasonable and apt use of the word, but it requires that we simultaneously juggle many meanings for "deposition." The use by the NCRP of the phrase "internally deposited" in the titles of some of its publications is unfortunate because it is not apt; "internally retained" is much more appropriate.

Many authors have urged the use of bias-free language (see, for example, Maggio 1991). The use of "daughters" for radioactive progeny or decay products is prevalent (Evans 1969; Hopke 1993; NCRP 1984a, 1984b, 1990) and defended by some (Muse 1994; Poston 1994). This use does not strike us and others (for example, Kearfott 1994a, 1994b) as unbiased language. There is nothing female or feminine, for example, about the short-lived alpha-emitting heavy metal atoms that are formed when ^{222}Rn undergoes a radioactive transition. "Progeny" or "decay products" are bias-free terms.

One of us (Strom) was puzzled on first encountering the term "chronic [health] effects" to refer to cancer, since the word "chronic" meant continuing over time, as in "chronic bronchitis." Sometimes authors have juxtaposed "chronic effects" with "acute effects," when they

Table 6. Summary of jargon and preferred terms.

Jargon	Preferred term
health physics	radiation protection or radiation safety
internal exposure (as in the event of taking material in)	intake
internal exposure (as in the dose due to an intake)	dose from internal radioactivity
internal exposure (as in process of being irradiated by radioactive material in the body)	irradiation by internal radioactivity
internal dosimetry	intake dosimetry
deposition (amount of activity in body or organ or tissue)	use retained quantity (alternative: body burden, organ burden)
internally deposited	internally retained
daughter	decay product or progeny
chronic effects	effects of chronic exposure or delayed effects, depending on which is meant
genetic effects	heritable ill-health
dose-response (by itself)	dose-response model, relationship, function
decay (as a quantum mechanical change in a nucleus)	transition
disintegration (as a quantum mechanical change in a nucleus)	transition
transformation (as a quantum mechanical change in a nucleus)	transition
cumulated activity	number of transitions
equilibrium absorbed-dose constant	energy absorbed per transition
ray	particle (α, β); photon (x ray, γ), or proton, neutron, etc.
swipe (test)	wipe (test)
smear	wipe (test)
dose rate (to communicate with public)	radiation level
activity (to communicate with public)	amount of radioactive material
activity	[expectation value of] transition rate [of radioactive material]
exposure (cause, e.g., exposure to uranium)	exposure
exposure (effect)	irradiation
exposure (to radon progeny, J h m^{-3} or WLM)	potential alpha energy exposure
exposure (to airborne radioactive materials, expressed as a product of a concentration standard and an exposure time, e.g., DAC-hours)	airborne radioactivity exposure
exposure (charge per unit mass)	massic ionization (C kg^{-1})
exposure rate	massic ionization rate (A kg^{-1})
absorbed dose	massic energy (Gy or J kg^{-1})
absorbed dose rate	massic power (Gy s^{-1} or W kg^{-1})
critical level, decision level	false alarm level (the lowest usable action level)
detection level, lower limit of detection, minimum detectable amount	advertising level or expected system capability

meant delayed effects such as cancer. One must distinguish between *chronic health effects* of radiation, such as radiation dermatitis, lymphocytopenia and even radiation pneumonitis, from *health effects of chronic irradiation.* This is a Kaplan Theorem 1 problem.

Many speak of "genetic effects" of radiation when the more precise term is "heritable ill-health." Cancer is a somatic effect, meaning that cancer occurs in the body of the person exposed as contrasted with a heritable effect, which occurs in the descendants of the person exposed. Radiogenic cancer, a somatic effect, is also a "genetic effect" in the sense that radiation damage to the genome is at least partially the cause: there are genetic changes in somatic cells that give rise to initiation, promotion, and or progression.

Using "dose-response" as a noun is really an incomplete thought, when specifically one means "dose-response relationship" or "dose-response model."

The word "decay" is a "snarl" word, with its connotation of bad or evil, such as tooth decay, urban decay, and moral decay. Thus, in the sense of diminution or attenuation, it is correct to speak of radioactive decay as the process in which the amount of some parent radionuclide diminishes. However, it is not apt to use "decay" for the quantum mechanical transition that occurs in a nucleus. When a ^{99m}Tc nucleus emits a photon to become ^{99}Tc, in a process called isomeric transition, nothing is "decaying." Certainly nothing is "disintegrating" (another "snarl" word in the sense of a negative connotation), nor is anything "transforming." The Medical Internal Radiation Dose (mird) Committees in the 1960's and 1970's introduced the term "transition," an apt word from physics that names the quantum-mechanical changes occurring in radioactive nuclei (e.g., Dillman 1969). Thus, radioactive transition is the correct term for what happens to an atom, be it the processes of alpha emission, beta emission, electron capture, isomeric transition, or spontaneous fission. Even though Calvin, of Bill Watterson's "Calvin and Hobbes," has said, "Verbing weirds language" (Fig. 6; Watterson 1993), we claim the statement "a ^{99m}Tc nucleus transitions to a ^{99}Tc nucleus" is specific and neutral. The transition, of course, is 1 Bq s.

"Cumulated activity" is an obscure term for "number of transitions" and contributes only obfuscation to communication. It is intuitive that the dose to an organ should be proportional to the number of radioactive

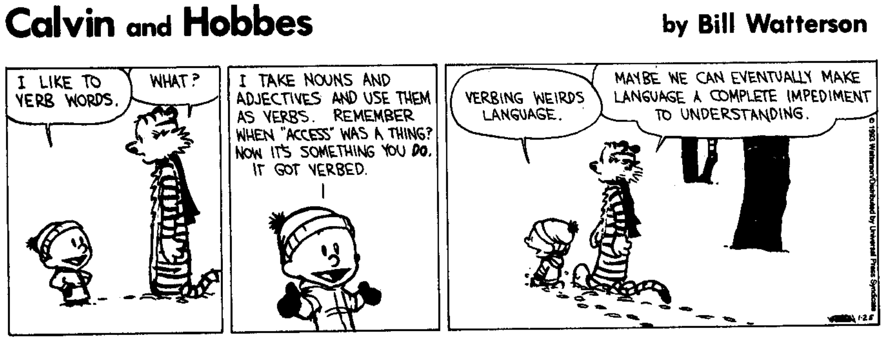

Fig. 6. Bill Watterson's "Calvin and Hobbes" discuss the discomforts of neology, one of the aspects of the English language that permits it to grow and change. CALVIN AND HOBBES © 1993 Watterson. Reprinted with permission of UNIVERSAL PRESS SYNDICATE. All rights reserved.

transitions that take place in the organ, and "number of transitions" is the preferred name for this quantity.

The mird committees also introduced the quantity "equilibrium absorbed-dose constant" for an infinite tissue-like medium, Δ_i, for the ith photon, expressed in the odd units "gram-rads per microcurie-hour." Kocher, in his excellent compendium (1981), continues this use. In plain English, this is the "energy absorbed per transition" in eV or J. A microcurie-hour is $37{,}000 \times 3{,}600 = 1.332 \times 10^8$ transitions. A gram-rad is 100 ergs $= 10^{-5}$ J $= 6.24 \times 10^{13}$ eV. Thus, a "gram-rad per microcurie hour" corresponds to the absorption of 7.51×10^{-14} J (0.469 MeV) per radioactive transition. The ICRP (1983) eliminated this obfuscation by using MeV [per transition] in place of g rad μCi^{-1} h^{-1}.

Along the same lines, a specific absorbed dose rate coefficient in SI units with no prefixes (Gy m^2 Bq^{-1} s^{-1}; read "grays per second at a meter from a becquerel") is the absorbed dose at a meter from a transition. The old specific gamma ray constants were proportional to the number of roentgens at a meter from a transition.

We have only a vague idea what a "ray" is. The concept of a beam, as in laser beam or x-ray beam, being a collimated bunch of photons going into a limited solid angle, makes sense. Also sensible are the concepts of microwave beams and radar beams, where both wave and particle characteristics of nonionizing radiation must be considered. A sun beam poking through the clouds is intuitive. But ionizing radiation is composed of particles, some of which are dominated by wave-like behavior in some circumstances. Alpha and beta particles, electrons, protons, neutrons, and photons are all particles. A baseball is a particle. It is hard to imagine what "baseball rays" would be. Thus, we suggest avoiding the word ray except in the context of x-ray photons or x-ray beams.

Both the word "swipe" and the word "smear" have negative connotations, so when measurements of removable surface contamination are made, "wipe" or "wipe test" is preferable.

When communicating with the public, the word "activity" has many connotations, but not "amount of radioactive material." We suggest uniform use of the latter as a simple device to avoid confusion.

As we have discussed above, the word "exposure" has a variety of meanings in radiological science. When it is used as the venerable quantity "charge liberated by ionizing radiation in air per unit mass," we suggest that the radiological scientist remember that it has the dimesions of massic charge, and should be called "massic ionization." When natural background produces an exposure rate of 2.85×10^{-9} C kg^{-1} h^{-1} (10 μR h^{-1}), the current per unit mass is, in SI base units with a prefix, about 0.717 pA kg^{-1}. Exposure rate has the dimensions of massic current, and should be called "massic ionization rate."

Since electrical power is (potential difference) $\times$ (current), and W_{air} = 33.97 eV per ion pair = 33.97 J C^{-1} = 33.97 V, 0.717 pA kg^{-1} $\times$ 33.97 V = 24.3 pW kg^{-1} or 24.3 pGy s^{-1}. Yes, absorbed dose rate is massic power, as is "specific absorption rate" in nonionizing radiation science. Absorbed dose is massic energy.

To the student who has learned the meaning of "massic," the above definitions make the quantities transparently simple in terms of basic concepts. Sometimes we wish that radiation protection had simply adopted the basic physics concepts and units instead of inventing one arcane name after another over the years.

In the nomenclature for the statistics of counting radioactive samples, we have communication chaos. There are two fundamental statistical concepts that have been badly named over the years. By "badly," we mean that the names have led to confusion.

The first concept is that of the lowest usable statistical action level, what we call the "false alarm level." This is the value of a count rate that is clearly not just a random fluctuation in background, but that indicates the presence of radioactivity over and above background. If the count rate exceeds this value, then the alarm sounds, and it's not a false alarm a given fraction of the time (e.g., 95%). This quantity was named the "critical level," L_C by Currie (1968), and the "decision level," DL, by other authors (e.g., HPS 1996). The latter is at least partially descriptive of what's going on. One of us (Strom) has electronically published a Health Physics Society Continuing Education Lecture on this subject (http://www.pnl.gov/bayesian/Strom/Stat-CEL-DJStrom.PDF).

The second concept is that of expected system capability, what we call the "advertizing level." This is the value of activity in a sample, which, if used with a pre-determined false alarm level in a particular system, results in a count rate above the false alarm level a given fraction of the time (e.g., 95%). This quantity was named the "detection level," L_D, by Currie (1968) and given the very poor name of "minimum detectable activity," *MDA*, by other authors (e.g., HPS 1996). Since activity less than this value can be routinely detected (with less than a 95% probability), the choice of *MDA* is particularly poor. Another name given to the advertizing level is "lower limit of detection," *LLD*, an equally poor choice since it isn't the lower limit of detection, and it is confused in the minds of the users with lower level discriminator (*LLD*) on a pulse-height analyzer. The advertizing level statistic doesn't function at all like a lower level discriminator, which lets no pulses below its threshold pass through. The advertizing level is a detection capability that a laboratory, such as a radiobioassay service laboratory, can legitimately claim in an advertizement. One should never compare measurements to the advertizing level (or the *MDA* or the L_D); one compares measurements instead to the false alarm level (or the *DL* or L_C).

The result of the poor names given statistical quantities is that very few radiation protection professionals understand them, they are very frequently misused (there are U.S. Federal regulations that mandate the misuse!), and many students struggle with the concepts. Many, particularly those who use "lower limit of detection," either use it to mean false alarm level or don't really know what it means or is used for, providing examples of both of Kaplan's theorems as well as our Theorem 3.

CONCLUSION

Radiation protection has acquired plenty of jargon over the years. We have shown how the use of jargon can lead to confused thinking or prevent clear thinking. While specialized concepts are needed, avoidance of arcane jargon helps communication within the profession and to other specialists and non-specialists. Guidance is available from dictionaries, other professions, and other languages. Some solutions we offer include adopting some new international usages, disaggregating terms, avoiding jargon, choosing specific and appropriate words, using and defining neologisms when they are needed, and knowing one's audience.

Acknowledgments—The authors wish to thank the many people who have contributed ideas, suggestions, and criticisms to this project. These include Paul S. Stansbury, Sydney W. Porter, Jr., Leonard M. Earls, Tom E. Huston, and George J. Vargo, Jr. Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO 1830.

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