# Conflicting Paradigms in Radiation Protection: 20 Questions with Answers from the Regulator, the Health Physicist, the Scientist, and the Lawyers

**Daniel J. Strom**
**Paul S. Stansbury**
Health Protection Department
Pacific Northwest National Laboratory
Richland, WA 99352-0999

**Sydney W. Porter, Jr.**
Porter Consultants, Inc.
Ardmore, PA 19003

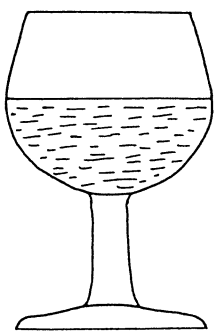
Reprinted with corrections from Strom, D.J.; Stansbury, P.S.; Porter Jr., S.W. Conflicting Paradigms in Radiation Protection: 20 Questions with Answers from the Regulator, the Health Physicist, the Scientist, and the Lawyers. pp.133-144 in: Mossman, K.L. ed. *Health Physics Training and Education.* Proceedings of the 28th Midyear Topical Meeting of the Health Physics Society. McLean, Virginia: Health Physics Society; 1995. PNL-SA-24763.

***Abstract***--George Orwell's "doublethink" should be generalized to "polythink" to describe the multiplicity of views that radiation protection professionals must simultaneously accommodate. The paradigms, that is, organizing principles and beliefs, that 1) regulators, 2) operational health physicists, 3) scientists, 4) lawyers for the defendant, and 5) lawyers for the plaintiff use in their approaches to radiation protection are presented. What we believe as scientists often conflicts with what we do for purposes of radiation protection. What we need to do merely to protect humankind and the environment from harmful effects of radiation is far less than what we must do to satisfy the regulator, whose paradigm has checklists, score-keeping, and penalties. In the hands of lawyers, our work must overcome different challenges. Even if the paradigms of the operational health physicist, the scientist, and the regulator match, the odds against the lawyers' paradigms also matching are astronomical. The differing paradigms are illustrated by example questions and answers. It is important for educators, trainers, and health physicists to recognize and separate the score-keeping, practice, science, and legal issues in health physics.

## INTRODUCTION

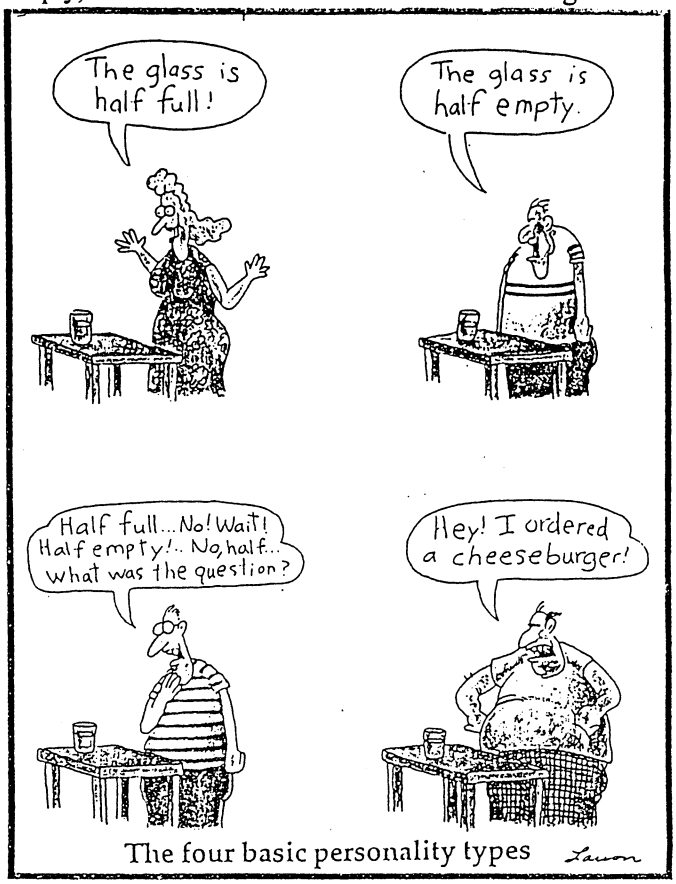
We intend to show how various points of view among five groups of people concerned with radiation protection matters may conflict or may result in misunderstanding, waste, or working at cross-purposes. The five groups are

- the "Regulator," who works for one of many government agencies and needs no definition
- the "Health Physicist," a hypothetical individual whose only interest is in protecting workers, the public, and the environment from the harmful effects of radiation (this hypothetical health physicist does not decide *whether* the radiation work will be done, but rather *how* it will be done from a radiation protection standpoint); he or she usually works for a DOE contractor or an NRC licensee
- the "Scientist," a person studying radiation or its effects, such as a radiation biologist, an epidemiologist, or a risk analyst
- the "Counsel for the Defendant," a lawyer representing the DOE, a DOE contractor, an NRC licensee, or another so-called "deep pocket" who is being sued for effects that the plaintiffs claim were caused by the defendant's use of radiation or radioactive materials
- the "Counsel for the Plaintiff," a lawyer representing one or more workers or members of the public (often "downwinders") who are suing the defendant.



Although a paradigm can be taken as a defining example, in this paper it means a set of organizing principles that allow one to understand and interpret the world. Paradigms allow us to filter the data and stimuli that surround us, and to extract

the information we need to make day-to-day decisions. Although useful, paradigms sometimes act as blinders. A simple example of conflicting paradigms is illustrated by glass of water filled to 50% of its capacity: one paradigm leads to the conclusion that the glass is half empty, a second leads to the conclusion that the glass is




half full, and still another leads to the conclusion that the glass is too big.

## TWENTY QUESTIONS

**Question 1:** Is there an amount of "dose" or quantity of radioactive material that is negligible?

***Regulator:*** Sometimes yes, usually no. In 10 CFR 30 is a list of concentrations exempt from licensing. However once radioactive material enters a licensed facility, ALARA expectations and record-keeping requirements take over. Everything measurable must be recorded, and everything recorded is examined in an ALARA review. Also, there is no floor to recording worker doses. (So, the regulated company's computer programmer devises a system which takes the 1 mSv from a worker's TLD and adds the 10 nSv from an intake of $^{3}H$, from about 3 net cpm in a 1 ml aliquot of urine, for a total effective dose of 1.00001 mSv).

***Health Physicist:*** There ought to be. In a typical smoke detector, which poses no danger to anyone, there are 180 ALIs of $^{241}Am$. The NCRP (1987 and 1993) has defined a negligible individual dose of 0.01 mSv $y^{-1}$ as a dose that can be disregarded. I don't understand why we in the health physics and regulatory community can't come up with practical ways to focus the regulations on the real problems.

***Scientist*** (Risk Analyst): People voluntarily, if unknowingly, accept radiation exposures through choices such as where they live, amount of air travel, diet, etc. Although the acceptability of a particular risk by an individual depends on whether the risk is imposed or voluntary, radiation doses the size of variations in natural background, that is, 0.1 to 1 mSv/y, ought to be of no concern to regulators.

***Counsel for the Defendant:*** Yes, of course. Amounts of radiation dose that are small with respect to natural background are negligible. The law does not concern itself with trifles ("De minimis non curat lex").

***Counsel for the Plaintiff:*** No. All radiation exposure has the potential to cause cancer and is, therefore, harm and injury.

**Question 2:** What does the "linear hypothesis" mean to you?

***Regulator:*** It is the scientific underpinning of all our radiation protection regulations. It is recommended by the highest authorities, the ICRP and the NCRP. It is one of the few subjects on which NRC and DOE agree with EPA.

***Health Physicist:*** The linear, no-threshold dose-response hypothesis has protected workers for years. It enables many practical things such as the adding of doses from one source or time to another. It is necessary for the ALARA philosophy to make sense.

***Scientist:*** The linear, no-threshold dose-response hypothesis is just that: a hypothesis. It is almost certainly not true for low doses or moderate doses delivered at low dose rates of low-LET radiation (NCRP Report No. 64). Hormesis and the biological effects of low level exposure (BELLE) are finally beginning to gain some credibility among thoughtful scientists. Most human data are consistent with a threshold or even a beneficial effect at low doses.

***Counsel for the Defendant:*** If the linear hypothesis is

wrong, it most certainly errs on the side of safety. Using it as the basis, the Defendant managed the workplace fairly, efficiently, and safely.

***Counsel for the Plaintiff:*** It is a scientific fact that explains how every dose of radiation is dangerous. However it is not perfect. Dose-response relationships are supra-linear in the low-dose region: look at the animal data for neutron exposures and the work of the good Dr. John Gofman.

**Question 3.** What's the difference between 49.99 mSv and 50.01 mSv?

***Regulator:*** The latter is clearly a violation; the former is a rather large exposure by today's standards. An overexposure will lead to an enforcement action. However, a dose as large the lesser will very likely receive significant regulatory scrutiny and may deserve action by us to improve licensee (or contractor) performance.

***Health Physicist:*** Oh, you mean difference between 4999 mrem and 5001 mrem -- that's 2 mrem. But this small difference may have a big influence whether I have a job with this employer a year from now.

***Scientist:*** Surely no one can measure radiation doses precisely enough to distinguish between 49.99 mSv and 50.01 mSv. This is a silly question.

***Counsel for the Defendant:*** The difference is insignificant.

***Counsel for the Plaintiff:*** The latter dose represents gross negligence on the part of the defendant and a dereliction of duty to my client, while the former is merely negligence. Furthermore, the difference will be four and a half million dollars in the jury award: $500,000 vs. $5,000,000.

**Question 4.** The International Atomic Energy Agency (IAEA) defines the concept of a national "competent authority" in matters involving the uses of radiation and radioactive materials. Who is the "competent authority" in the USA?

***Regulator:*** Knowledgeable officials exercising authority over matters relating to radiation exist in many government agencies, including the Department of Defense (DOD), the Department of Energy (DOE: Office of Nuclear Safety, ONS; Environment, Safety and Health, EH; others), the Department of Transportation (DOT), the Environmental Protection Agency (EPA), Federal Aviation Administration (FAA), the Food and Drug Administration - Center for Devices and Radiological Health (FDA-CDRH), the Mine Safety and Health Administration (MSHA), the National Aeronautics and Space Administration (NASA), the Nuclear Regulatory Commission (NRC), the Postal Service, and the States. Also, recommendations and/or standards used by regulatory agencies come from the American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME), the American Society for Testing and Materials (ASTM), the Centers for Disease Control and Prevention (CDCP), the International Atomic Energy Agency (IAEA), the International Air Transport Association (IATA), the International Civil Aviation Organization (ICAO), the International Commission on Radiological Protection (ICRP), the Institute of Electrical and Electronic Engineers (IEEE), the International Maritime Organization (IMO), the Institute of Nuclear Power Operations (INPO), the International Organization for Standardization (ISO), the Joint Commission on the Accreditation of Healthcare Organizations (JCAHO), the National Academy of Sciences (NAS), National Council on Radiation Protection and Measurements (NCRP), the Nuclear Energy Agency (NEA), the National Institutes of Health (NIH), National Institute of Occupational Safety and Health (NIOSH), and the National Institute for Standards and Technology (NIST), as well as from many professional societies such as the American Association of Physicists in Medicine (AAPM), the American College of Radiology (ACR), the American Council of Governmental Industrial Hygienists (ACGIH), the American Medical Association (AMA), the American Nuclear Society (ANS), Health Physics Society (HPS), and the Society of Nuclear Medicine (SNM); and from insurance companies.

***Health Physicist:*** It depends on the context. I first have to figure out where the radiation came from, then I know who's in charge. Sometimes exposure comes from NRC-licensed activities or State-licensed activities, and sometimes it comes from natural background, airport x-ray machines, air travel, and/or medical procedures. Occasionally, regulated radioactive materials may become unregulated, such as isotopes administered to patients for diagnosis or therapy, those resulting from fallout from atmospheric nuclear weapons testing, and those resulting from an international nuclear accident. Other radiation sources

never were regulated, such as indoor radon at home or in buildings, or cosmic radiation at high altitudes.

***Scientist:*** This isn't a scientific question.

***Counsel for the Defendant:*** The governmental agencies have large staffs of experts who agree about radiation matters.

***Counsel for the Plaintiff:*** Competent? Did I hear you correctly? Who said anything about competent?

**Question 5:** Does it matter whether doses are received at a high dose rate or low dose rate?

***Regulator:*** No, as long as it's less than 50 mSv in a calendar year. For a declared pregnant woman, a uniform dose rate not to exceed 0.5 mSv/month is to be desired.

***Health Physicist:*** I'm nervous about Very High Radiation areas. A worker can get a big dose before one has time to correct any improper actions.

***Scientist:*** Yes, it does matter. If there is no time for repair during irradiation, then radiation sub-lesions can interact to form lesions. If repair occurs during irradiation, then some sub-lesions will be repaired before they can interact with other sub-lesions to cause injury. Low LET radiation at a low dose rate has a much smaller risk of harm per unit dose than that at a higher dose rate.

***Counsel for the Defendant:*** Of course it matters. At low dose rates, there is repair.

***Counsel for the Plaintiff:*** Of course not. Radiation is radiation. Any or all of it can cause cancer, just like the dreadful disease my client has.

**Question 6:** You simply can't buy a rare hamburger in a restaurant in the USA since the *E. coli* O157:H7 incidents, and food irradiation would solve this and many other public health problems. Why is the public still denied the benefits of food irradiation when its safety has been established, it is legal in other countries, and it is already used on many spices sold in this country?

***Regulator:*** We're working on it. Resolving issues where there are strong concerns and feelings by public groups takes time.

***Health Physicist:*** More than 30 years worth of research has shown that the process is safe and effective. Why can't the NRC just license facilities and let them get started?

***Scientist:*** There is no scientific reason why foods can't be irradiated to eliminate biological contamination. It's done for our astronauts and used in other countries such as Canada. However one of the things I just don't understand is how activists, with the betterment of mankind at heart, can oppose food irradiation while people in the world are starving.

***Counsel for the Defendant:*** Like boiling, baking, drying, salting, and freeze-drying, food irradiation is simply another means of processing food. None leave the food unaltered; all are better than spoiling. Now let me respond to the arguments raised by my distinguished colleague on the other side of the aisle. In law, we don't *count* the evidence, we *weigh* it. Likewise, scientists don't *count* studies on one side or the other of an issue, they *weigh* the studies' results by judging the quality of design and analysis, adequacy of control subjects, thoroughness, size, bias of the researchers, and many other factors. One well-designed, well-executed study of sufficient size and statistical power is worth more than countless poorly designed or poorly executed studies.

***Counsel for the Plaintiff:*** My client's condition was obviously caused by the radiation that was put into this food. Hundreds of studies have shown food irradiation to be dangerous.

**Question 7:** Current regulations require considerable record-keeping. What records are really necessary?

***Regulator:*** Our job is to protect workers, the public, and the environment from radiation. Without accurate detailed records by the licensee (or DOE contractor), we can't do our job.

***Health Physicist:*** We could do with a lot fewer records. Sure, we have to be able to demonstrate that doses and releases were within the limits, that we had a good radiation protection program, and that we followed it. ALARA committee minutes, copies of instrument control charts and the data they were derived from, detailed investigations of trivial incidents, all of these are more and more records, and yet the workplace is not becoming more and more safe. Eliminating the requirements for most of these records (and their inspection) would not affect radiation protection, environmental protection, or public safety at all, other than to free up society's resources for real problems.

***Scientist:*** When you vacuum your house, do you keep records? When you check the oil on your car, and it's the same as the last time you checked it, do you keep records? No, of course not. Do you save your grocery lists once you've bought your groceries? No. Too often we're talking about trivial levels of radiation exposure (or at least non-existent levels of risk). There are tremendous consequences for failure to maintain records to the level expected by the inspector. However there is a tremendous cost in terms of time and brain-power resources.

***Counsel for the Defendant:*** Detailed, accurate, complete, and understandable records are essential to defending yourself against a litigant who will claim radiation exposure (along with your negligence) from many years ago caused his cancer. Paper is the only thing you can bring into the courtroom to defend yourself. The next time your boss questions the amount of time and money you spend on record-keeping and associated QA, remind him that his name will likely be on the lawsuit, too.

***Counsel for the Plaintiff:*** The records show that the Defendant deliberately exposed my client to radiation. Yet the records are not completely acceptable. The regulators were often critical. Does this lack of completeness mean the Defendant was trying to cover up something, or does it merely indicate that the Defendant and his radiation protection staff were careless or poorly funded? You don't really need the answer to that question to make things right for my client.

**Question 8.** Should we change to SI units in radiation protection?

***Regulator:*** No. It will confuse people and cause hazardous situations because workers and technicians will not recognize dangerous levels of radiation.

***Health Physicist*** (who learned the trade in "traditional" units)**:** No, I agree with the regulator.

***Younger Health Physicist*** (who learned the trade in SI units): Yes. SI units are simpler for use in calculations and simplify teaching immensely. Experience in other countries, such as the United Kingdom, has proved that a clean break with the past is quick and effective. It will enhance international competitiveness.

***Scientist:*** Yes, of course. Everyone else in the world has done it, and all of the scientific literature is in SI units. The calculational advantages are numerous; the practical drawbacks minimal. The current use of two systems of units leads to imprecisions due to unit conversions and subsequent rounding.

***Counsel for the Defendant:*** No, all of the records are in traditional units. If we change to SI units now we will have to educate all future juries.

***Counsel for the Plaintiff:*** This is trickery. The sievert is 100 times bigger than the rem. I won't let the jury be fooled into thinking smaller numbers mean less danger.

**Question 9.** What does "conservative" mean?

***Regulator:*** Being conservative means erring on the side of safety.

***Health Physicist:*** Usually being conservative means erring on the side of overestimating dose, so that the worker will apparently reach the dose limit earlier, rather than later, and thus be removed from further exposures by administrative controls. Being conservative means "erring on the side of safety" by making assumptions that, if in error at all, err on the side of overestimating doses.

***Scientist:*** Conservative means that whatever goes in, comes out, such as conserving energy and momentum in elastic collisions.

***Counsel for the Defendant:*** It means that almost every dose ever recorded is too high, sometimes way too high, compared to the truth.

***Counsel for the Plaintiff:*** Conservative means taking short cuts in measuring or calculating the true dose and skimping on radiation protection, allowing the defendant to conserve financial resources.

**Question 10.** What is the role of professional judgment in radiation protection?

***Regulator:*** Professional judgment is unnecessary if procedures are excellent (with all possibilities anticipated), if workers are trained, and if procedures are followed to the letter.

***Health Physicist:*** Situations always arise that cannot be foreseen and require trained, experienced radiation protection personnel to judge what to do.

***Scientist:*** If health physicists had any professional judgement, they'd become real scientists.

***Counsel for the Defendant:*** My client hired trained, experienced, credentialed radiation protection professionals so that their maturity, education, and judgement would ensure that the workplace remained safe.

***Counsel for the Plaintiff:*** The defendant's radiation protection staff made a habit of finding clever ways to get around the regulations and do things illegally, or at least cheaper.

**Question 11.** What does "deposition" mean?

***Regulator:*** In DOE's RadCon Manual, its the amount of radioactivity one has in the body from an intake.

***Health Physicist:*** Well, depending on the context, it means a) the quantity of radioactive material in the respiratory tract following an inhalation or in the stomach following an ingestion, b) the process of material from systemic circulation winding up in a tissue or organ (for a while), c) the physical processes of material getting onto the skin or surfaces of the lung, or d) an amount of radioactive material in a whole body or particular tissue (a time-varying retained quantity).

***Scientist:*** Where does tritium "deposit" in the human body? Where does cesium "deposit" in the body? These materials are just passing through. We should stick to the term *retained quantity* as used by the ICRP and in DOE's Implementation Guide for Internal Dosimetry Programs, and *intake* for the amount taken in and the event of taking in radioactive materials. *Deposition*, as defined by the ICRP, is the process of aerosol particles landing on, and sticking to, a surface, such as the airways of the respiratory tract, with *Deposition fraction* having a clearly defined meaning.

***Counsel for the Defendant:*** Taking sworn testimony from a witness outside of a courtroom.

***Counsel for the Plaintiff:*** For once, my esteemed colleague makes sense.

**Question 12.** What can you say for sure about the air that passes through the filter of a breathing-zone (BZ) air sampler?

***Regulator:*** The radioactive materials removed from it may be used to assess the concentration of airborne radioactive materials breathed by the worker.

***Health Physicist:*** The person wearing the BZ sampler *didn't* inhale the radionuclides in *that* air.

***Scientist:*** The inference of risk from doses which were inferred from intakes which were inferred from exposures which were inferred from the radioactivity filtered from the air is a process fraught with uncertainties so large as to be nearly fantasy.

***Counsel for the Defendant:*** The filter in question was probably contaminated in handling, and the activity on it came not from the air the plaintiff breathed, but from someone's dirty hands.

***Counsel for the Plaintiff:*** My client was breathing air that was much more contaminated than that measured by the BZ air sampler, which was not representative of the poisonous atmosphere that the defendant forced workers to breathe.

**Question 13.** Why is there so much paperwork, reporting and record keeping associated with dosimetrically minor intakes of radioactive materials or dosimetrically minor skin contamination incidents when there is no paperwork, reporting, and record-keeping associated with comparable external exposures?

***Regulator:*** The public, the radiation workers themselves, and their families insist that radiological hazards be left in the workplace. Of course, we place special emphasis on preventing the internal and external contamination of workers.

***Health Physicist:*** Because the old mind-set about intakes being unacceptable and representing a "loss of control" still permeates regulations such as the DOE RadCon Manual. Currently, when a worker gets contamination on his or her skin, or inhales radioactive materials, management pays lots of attention to the incident, almost regardless of dose. Numbers of skin contamination incidents or intakes are "performance indicators" for radiation protection programs in the DOE, whether dosimetrically significant or not.

***Scientist:*** This is clearly not a risk-based system of protection, but a system driven by perceptions about radiological control being more important than radiological protection.

***Counsel for the Defendant:*** In this litigious society, my client has been driven to document even minute incidents by the greed of the learned counsel for the plaintiff and his ilk and those seeking a deep pocket to sue. This comes at tremendous cost to society, to our

productivity, and to our international competitiveness.

***Counsel for the Plaintiff:*** Ladies and gentlemen of the jury, the defendant is clearly so tight-fisted and callous that he shirks even the most basic duty of care for my client and other workers: not only does he expose them to lethal poisons while they toil, but he whines about even keeping track of it due to "cost" or "inconvenience."

**Question 14.** What is As Low As Reasonably Achievable (ALARA)?

***Regulator:*** A requirement of 10 CFR 20, 10 CFR 835, and the RadCon Manual that licensees/contractors can be inspected against and be subject to enforcement actions for poor performance.

***Health Physicist:*** A philosophy, a way of thinking, a process for minimizing doses consistent with expenditures and getting the job done.

***Scientist:*** An optimization process involving the solution of differential equations whose variables include the dollar cost of a human life and the costs of protection.

***Counsel for the Defendant:*** A goal to strive for but not a standard, requirement, or duty.

***Counsel for the Plaintiff:*** The *minimum* standard of operating practice, which was clearly violated while the plaintiff was working for the defendant.

**Question 15.** Of what use are dosimetry and bioassay measurements?

***Regulator:*** These results are used to demonstrate that workplace controls are effective or to prove non-compliance. Also, results in excess of certain levels may trigger prompt reporting requirements.

***Health Physicist:*** I use these results to be sure I'm protecting workers from radiation and that everything is working as planned, and also to provide peace of mind to workers by demonstrating that the workplace is safe and that the *individual* worker has been exposed to acceptable levels of radiation.

***Scientist:*** These measurements are made so I can learn about the effects of radiation on people by developing a dose-response curve.

***Counsel for the Defendant:*** These results are needed so we can prove that the defendant probably didn't harm the plaintiff.

***Counsel for the Plaintiff:*** If the defendant had actually made adequate measurements, we could use them to prove that he is guilty; however, his measurements barely represent the tip of the radiation iceberg to which my client was exposed.

**Question 16.** Regulatory dose limits are now expressed in terms of total effective dose equivalent (TEDE). What is the relationship of the dose recorded on a person's external dosimeter to TEDE?

***Regulator:*** The deep dose equivalent, $H_d$, may be used in place of effective dose equivalent from external irradiation. However, to use anything other than the badge dose, you'll have to demonstrate it's justified, approved by us in advance. Yes, what's needed for justification may resemble a mini research project.

***Health Physicist:*** In most cases, $H_d$ is close enough to TEDE to be good enough to protect workers, even though it's likely to overestimate TEDE.

***Scientist:*** The deep dose recorded on a dosimeter is always more than the TEDE, especially for thermal neutrons and low energy photons. For some nuclides, such as $^{125}I$, $H_d$ may overestimate TEDE by a factor of 3. And, when radiology workers are wearing lead aprons, $H_d$ very seriously overestimates TEDE. Recording just the TEDE will really confound future epidemiological studies.

***Counsel for the Defendant:*** The badge readings are adequate to show that the exposures were very low.

***Counsel for the Plaintiff:*** Through simple human oversight, my client wasn't wearing his badge the day he worked in that deadly radiation field, and even if he had been, there are serious doubts about the accuracy and relevance of the numbers the defendant claims.

**Question 17.** What does "internal exposure" mean?

***Regulator:*** As used in DOE's RadCon Manual, it means getting a radiation dose from an intake of radioactive materials. The phrase doesn't occur in 10 CFR 835 and 10 CFR 20.

***Health Physicist:*** It's the opposite of external exposure. It means you're being exposed to radiation from an

internal source, as opposed to an external source.

***Scientist*** (Toxicologist)***:*** "Internal exposure" is an oxymoron that betrays fuzzy thinking on the part of health physicists. In the workplace or environment, one may be *exposed* to airborne radioactive materials. If there is an intake of these materials via inhalation, ingestion, absorption through intact skin, or passage through an open wound, then one may be *irradiated* by the materials from within the body. One might sensibly talk about "internal irradiation," but the *exposure* occurs outside (external to) the body, and the *irradiation* occurs due to radioactive materials inside (internal to) the body. All organs or tissues that are irradiated are inside (internal to) the body, regardless of whether the source is inside or outside of the body. Furthermore, exposure is often used to refer to the product of a concentration (sometimes normalized to DACs) and a stay time, e.g., DAC-hours or Working Level Months, a product historically used to calculate a crude estimate of what entered a worker's nose and mouth.

***Counsel for the Defendant:*** Dose is dose, whether received from radioactivity inside the body, as from an internal exposure, or from radioactivity outside of the body, as from an external exposure.

***Counsel for the Plaintiff:*** Internal exposure is a deceitful euphemism for carrying radioactive poisons around in your body, probably for the rest of your life, caused by the defendant's failure to provide a safe and healthy workplace.

**Question 18.** How should we limit hot particle exposures of the skin?

***Regulator:*** According to 10 CFR 835.205 (b), there are different ways of assessing and controlling the skin dose depending on whether over 100 $cm^2$, between 10 and 100 $cm^2$, or less than 10 $cm^2$ are affected. The hot particle would fall into the category of under 10 $cm^2$ (e.g., a circle of radius $\leq$ 1.7 cm).

***Health Physicist:*** The NCRP Report 106 method of limiting total beta exposure to 75 μCi·h makes sense. Emphasis on doses to small parts of the body (except the lens of the eye) is not sensible. However, I learned that we should always *prevent* deterministic (nonstochastic) effects, and this limit may not do that.

***Scientist:*** Local skin irradiation by a hot particle often is no more serious than a paper cut. Dose is not a very meaningful concept for extremely nonuniform irradiation from hot particles. Cells in contact with the particle may receive astronomical doses with little or no health consequence to the individual. To limit deterministic effects, no more than $10^{10}$ beta particles should be emitted (equivalent to a time-integrated activity of $10^{10}$ Bq·s or 75 μCi·h) while the particle is in contact with the skin (NCRP Report No. 106). This limit will effectively limit skin cancer, since only a small portion of the skin in being irradiated.

***Counsel for the Defendant:*** The scientist is right: an injury equivalent to a paper cut is trivial.

***Counsel for the Plaintiff:*** My client's skin received a localized dose of 510 mSv; the limit for any tissue is 500 mSv. Clearly, the defendant breached his duty to protect my client in the case of this hot particle.

**Question 19.** Is a committed, effective millisievert from internal irradiation the same as an acute effective millisievert from external irradiation?

***Regulator:*** Yes.

***Health Physicist:*** Not the way I read the regulations: In 10 CFR 835 and DOE's RadCon Manual, posting for an Airborne Radioactivity Area is required at >10% of a DAC, a threshold corresponding to 2.5 μSv/h, while posting for a Radiation Area is required at 50 μSv/h. In 10 CFR 20, posting for an Airborne Radioactivity Area is required at ≥30% of a DAC, a threshold corresponding to 7.5 μSv/h, while posting for a Radiation Area is required at 50 μSv/h. This disparity indicates that regulators still believe that a millisievert from intakes of radioactive materials is more serious than a millisievert from external irradiation. Furthermore, for *planning* radiation protection, I would say that it's okay to treat them as equivalent, but not for keeping track of actual workers' doses (that is, *score-keeping*).

***Scientist:*** No, they are certainly not the same on a risk basis. Even under a linear, no-threshold dose-response relationship the risk from an inhalation intake of 1 ALI of class W $^{239}Pu$ is significantly lower (by a factor of 10 when comparing a 20-year-old woman to a 65-year-old man) than the risk from 50 mSv acute external radiation exposure due to the fact that cancer risk decreases strongly with age at exposure, and the last doses from the intake occur 50 years after the acute exposure, thereby conferring significantly lower risk.

***Counsel for the Defendant:*** Committed effective dose

is a bookkeeping technique used by radiation protection professionals to combine radiation doses from various types of radiation by various routes of irradiation, and covers 50 years after intake. It is no more valid to score this dose as having accrued to a worker on the day of the intake than it is to claim that you have paid off your mortgage on the day the loan is approved: it hasn't happened yet. In this case, the plaintiff's cancer was diagnosed 5 years after the intake, with 45 years yet to run on the committed dose clock. Counsel for the plaintiff claims harm from a dose most of which hadn't even been received yet, an obviously fallacious claim.

***Counsel for the Plaintiff:*** My client's body contains poisonous radioactive materials, ticking away like a time bomb inside of him, invading his vital organs with toxic nuclear radiation, producing unspeakable damage to his genes, and unleashing this deadly disease. The intake in question resulted in a committed effective dose of 60 mSv, clearly in excess of regulatory limits, and so the defendant should be held responsible.

**Question 20.** Relative biological effectiveness of some *test* radiation is defined as

$$RBE_{test} = \frac{D_{250\ kVp\ x\ rays}}{D_{test}},$$

where $D_{250\ kVp\ x\ rays}$ is the dose of 250 kVp x rays that produces the same effect at $D_{test}$ of some test radiation like αs or neutrons. What would radiation protection be like if the standard reference radiation for calculating relative biological effectiveness had been alpha radiation instead of filtered 250 kVp x rays or if *RBE* were defined as a *ratio of effects* at the same dose instead of a *ratio of doses* that produce the same effect?

***Regulator:*** Ask a scientist.

***Health Physicist:*** I and many of my colleagues would be out of a job.

***Scientist:*** If *RBE* were redefined with α radiation as the standard radiation, or as a ratio of effects, radiation protection would be unrecognizably changed. Many scientists have said that *RBE* is upside down or has the wrong reference radiation (which is currently 250 kVp x-rays because this was easy to produce in many laboratories across the country in the 1920s and 1930s). *RBE* is a ratio of doses that produce the same effect. If $RBE_{test}$ were defined as

$$RBE_{test} = \frac{D_{\alpha}}{D_{test}},$$

(that is, $D_{\alpha}$ substituted for $D_{250\ kVp\ x\ rays}$), the result would be dramatically different. A dose, $D_{test=\gamma\ or\ \beta}$, of 1 or 10 mGy of gamma or x-ray photons or betas produces no effect. The dose of alpha radiation, $D_{\alpha}$, that produces no effect is 0. Thus, $RBE_{\gamma} = RBE_{\beta} = 0$. Quality factors in this system, $Q_{\alpha}$ and $Q_{\beta}$, would be zero since they are based on *RBE*s. Low doses of low-LET radiation would be ignored under such a system. Now consider a system in which $RBE_{test}$ is defined as a ratio of effects for the same absorbed dose,

$$RBE_{test} = \frac{E_{test}}{E_{250\ kVp\ x\ rays}},$$

where $E_{test}$ is the *effect* of the test radiation and $E_{250\ kVp\ x\ rays}$ is the *effect* of 250 kVp x rays, both at the same absorbed dose $D_{test} = D_{250\ kVp\ x\ rays}$. In this system, the *RBE* of high linear energy transfer (high-LET) radiation at 1 or 10 mGy would be infinite ($RBE_{high\ LET} = \infty$), since $E_{250\ kVp\ x\ rays} = 0$, there are no observable effects in these dose ranges for most endpoints for 250 kVp x rays. This would not work very well, so one could use a high-LET radiation such as α-radiation as the standard. Then $RBE_{test}$ would be

$$RBE_{test} = \frac{E_{test}}{E_{\alpha}},$$

At doses of 1 to 10 mGy in this system, $Q_{\alpha} = 1$, and $Q_{\gamma} = Q_{\beta} = 0$ (because they are derived from *RBE*s). Low doses of low-LET radiation would be ignored under such a system.

***Counsel for the Defendant:*** We have been saying all along that low doses of low-LET radiation are harmless, and the scientist has shown that radiation protection at these levels is unnecessary.

***Counsel for the Plaintiff:*** We know that all radiation exposure carries risk. The jury should not be confused by such hypothetical scientific fantasies.

## CONCLUSIONS

These questions illustrate some of the conflicting paradigms encountered daily in radiation protection. In

reality, many persons calling themselves "health physicists" simultaneously wear several hats, juggling several of these points of view. Health physicists have conflicts when they try to meet the requirements of regulators, managers, workers, and the public, all the while considering what they know as scientists. Also, there are many thoughtful, competent, professional, and scientifically trained individuals who are "regulators," in the U.S. DOE, the NRC, and in other federal and state agencies. Their roles are essential, and this work is not intended to be "regulator bashing." Rather, we have tried to illustrate the differences in perspectives resulting from different priorities:

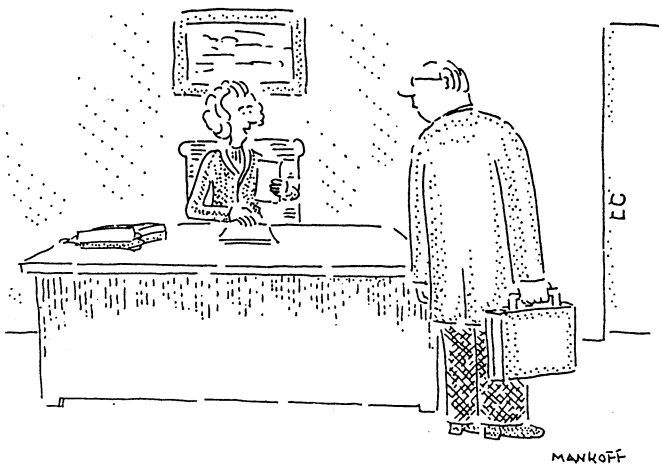
- regulatory requirements for radiation protection programs whose existence and efficacy must be documented
- worker and environmental protection while getting the job done
- adherence to scientific understanding of radiation, often too detailed for practical use
- the legal standpoint of putting radiation in perspective as a causal agent among many causal agents, which involves selecting the best "experts" to support the case
- the legal standpoint of invoking outrage about the dangers of radiation, which involves selecting the best "experts" to support the case.

Health physicists must maintain a sometimes difficult level of "doublethink" in order to carry out their professional responsibilities. There's nothing wrong with qualifying statements by beginning, "For purposes of radiation protection..." when what is done for radiation protection differs from what health physicists believe as scientists. Also, those who train health physicists need to introduce them to the reality of the differing perspectives an individual might have about radiation protection, depending on viewpoint.

***Disclaimer***--The opinions expressed in this document are solely the responsibility of the authors, and do not necessarily reflect those of the DOE or any other regulatory agency, or of the Battelle Memorial Institute.

***Acknowledgements***--The authors would like to thank many people for helpful discussions and ideas, including (in alphabetical order): George R. Cicotte, Kenneth P. Ferlic, Eva E. Hickey, David P. Higby, Michael W. Lantz, Leo H. Munson, Charles E. Roessler, Jerry C. Rosen, Michael A. Sheetz, Gregory A. Stoetzel, and George J. Vargo, Jr. This work was supported by the U.S. Department of Energy under Contract No. DE-AC06-76RLO 1830.

THE NEW YORKER, NOVEMBER 27, 1995




*"Sir, the following paradigm shifts occurred while you were out."*