

TEN PRINCIPLES AND TEN COMMANDMENTS OF RADIATION PROTECTION[†]

Daniel J. Strom*

Abstract—For decades, the phrase “time, distance, and shielding” has been presented as summarizing the “basics” of radiation protection. Indeed, for protection from external radiation sources, these three principles are probably the most important ones on which a worker can make decisions and take actions. However, these principles do not address protection against intakes of radioactive materials or “ontakes” (skin contamination), other risk-limiting measures, or other important protective measures taken by governments, public health agencies, regulators, and institutional programs (measures such as performance standards, health education, facility engineering requirements, and administrative procedures). I have identified ten principles and ten accompanying commandments of radiation protection: time, distance, dispersal, source reduction, source barrier, personal barrier, decorporation, effect mitigation, optimal technology, and limitation of other exposures. Corresponding non-technical forms of the commandments are hurry (but don’t be hasty); stay away from it; disperse it and dilute it; use as little as possible; keep it in; keep it out; get it out or off of you (after intake or skin contamination); limit the damage; choose the best technology (perhaps a non-radiation technology); and don’t compound risks (don’t smoke). Technical versions of the commandments are also provided using the verbs “optimize,” “maximize,” or “minimize.” Not all commandments can be applied at the same time, and application may be different for workers and members of the public. Advantages, disadvantages, and implementation of these principles and commandments are discussed, and numerous examples provided. The application of the principles and commandments must be based on knowledge of the radiological conditions to be managed.

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INTRODUCTION

DECISION ANALYSTS study how people make decisions, what principles they apply, what information they need and use, what choices they can and do make, and how

* Health Protection Department, Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352.

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they behave. The spectrum of decisions one can make about radiation protection, and actions one can take, depends on where one fits into the world of radiation protection. Radiation workers make very different kinds of decisions and choices than do legislators and regulators. The former are often concerned with managing their own personal dose, while the latter are concerned with managing doses for populations or society as a whole. A radiological protection technician may make decisions about reduction of exposure time, increasing of distance between a worker and a source, moving some shielding, or waiting to enter an accelerator target room until short-lived activation products have decayed. A physician may make decisions about choices between radionuclides, weighing options between dose averted, and allergic reactions for blocking agents. An individual responsible for emergency response may have to decide whether to evacuate and whether to administer prophylactic iodine. A legislator or regulator may make decisions about electrical energy production, radon-reducing new home construction, or differences in magnitude and acceptability of risk for different populations, such as unborn children, patients, or minors.

This paper represents one health physicist’s attempt to understand and codify the principles and actions taken at all levels of radiation protection. Clearly, not all principles can be applied simultaneously to many radiation protection situations. Furthermore, it is fundamental to all radiation protection that the application of the principles and commandments must be based on knowledge of the radiological conditions to be managed. Thus, surveys, monitoring results, knowledge of source strength and nature, and knowledge of other conditions are the foundation on which all of radiation protection is built.

THE NEED FOR PRINCIPLES AND COMMANDMENTS

For decades, the phrase “time, distance, and shielding” has been presented as summarizing the “basics” of radiation protection. Indeed, for protection from external radiation sources, this easily-remembered list of three variables should remind workers of the most common decisions and actions needed to minimize external irradiation. However, this list of variables is not complete even for external irradiation, since it omits the variable of

decay time (as opposed to exposure time) (Strom 1988). The three variables “time, distance, and shielding” only partially address protection against intakes of radioactive materials, other risk-limiting measures, or other important protective measures taken by governments, public health agencies, regulators, and institutional programs (measures such as performance standards, health education, facility engineering requirements, and administrative procedures). Furthermore, “time, distance, and shielding” simply do not apply to many radiation protection situations, such as indoor radon. And finally, the standard liturgy of “time, distance, and shielding” doesn’t tell the worker what action to take. For these reasons, I have chosen to separate the principles (short names) from the commandments (what to do).

I have identified ten principles and ten accompanying commandments of radiation protection (Table 1). Nine apply to all radiation sources: time, distance, dispersal, source reduction, source barrier, personal barrier, effect mitigation, optimal technology, and limitation of other exposures; and one applies only to internal and surface sources: decorporation. The corresponding non-technical commandments are hurry (but don’t be hasty); stay away from it; disperse it and dilute it; use as little as possible; keep it in; keep it out; get it out or off of you (after intake or skin contamination); limit the damage; choose the best technology (perhaps a non-radiation technology); and don’t compound risks (don’t smoke). Commandments are given in Table 1 in both their non-technical and technical forms, the latter involving minimization, maximization, or optimization.

PRINCIPLES AND COMMANDMENTS

Time

- At a constant dose rate, radiation dose is proportional to time to the first power. Similarly, at constant

concentration and constant breathing rate, the amount of activity inhaled (the “intake”) is also proportional to time to the first power. The commandment for persons in a radiation field or in a radioactive atmosphere is to *hurry (but don’t be hasty)*, or *minimize the exposure or intake time*.

The advantages of the time principle are that it is the least expensive, and affords dose reductions of up to perhaps a factor of 10. The disadvantage is the limited dose reduction that may be available. The implementation of this principle for shielding diagnostic radiology facilities has focused on understanding of “occupancy” and “use” factors (the occupancy is the fraction of the time that a space is occupied by people, while the use factor is the fraction of the time that the radiation is aimed in a particular direction). For operations involving radioactive sources such as preparation of radiopharmaceuticals, or maintenance work in a high radiation area, rehearsing operations with non-radioactive sources often will reduce exposure time. For large, complex jobs in defense or electric generation, exposure time can be reduced by planning and practice with non-radioactive facilities and equipment. For operations using radiation on people, use of the minimum amount of radiation consistent with the desired diagnostic information reduces exposure. For physicians, minimizing fluoroscopy on-time minimizes exposure.

Distance

The distance principle has a purely geometric component. For sufficiently great distances, it also includes a component of absorption. Absorption is covered below under source barrier and personal barrier.

Radiation dose rate from external irradiation in a vacuum (to eliminate absorption) is inversely proportional to the square of the distance for a point source. For

Table 1. Principles and commandments of radiation protection.

Principle	Commandment (familiar)	Commandment (technical)
1. Time	Hurry (but don’t be hasty)	Minimize exposure/intake time
2. Distance	Stay away from it; stay upwind	Maximize distance
3. Dispersal	Disperse it and dilute it	Minimize concentration, maximize dilution
4. Source reduction	Use as little as possible	Minimize production and use of radiation and radioactive material
5. Source barrier	Keep it in	Maximize absorption (shield); minimize release (contain and confine it)
6. Personal barrier	Keep it out	Minimize entry into the body of radiation and radioactive materials
7. Decorporation (internal and surface irradiation only)	Get it out of you and off of you	Maximize removal or blocking of materials from the body (after intake or skin contamination)
8. Effect mitigation	Limit the damage	Optimize exposure over time and among persons, scavenge free radicals, induce repair
9. Optimal technology	Choose best technology	Optimize risk-benefit-cost figure
10. Limitation of other exposures	Don’t compound risks (don’t smoke)	Minimize exposures to other agents that may work in concert with radiation (e.g., genotoxic agents or those that may cause initiation, promotion, or progression of tumors)

non-point source geometries, the geometric component of the distance principle becomes less important: in a vacuum, radiation dose rate is inversely proportional to distance to the first power for an infinite line source, and radiation dose rate is independent of distance for an infinite plane source.

Intakes of radioactive material from a radionuclide source that is leaking can also be limited by maximizing the distance between the exposed individual and the source, since dilution will likely reduce intake with increasing distance. Obviously, the likelihood and severity of skin contamination also decreases with distance.

Control of the distance between the source and the subject is an important principle. The vernacular commandment is *stay away from it*. The technical commandment for this principle is *maximize the distance between the source and the subject*.

Advantages of maximizing distance include dose reductions, in an occupational setting, of 10^{-1} to 10^{-4} . Disadvantages include moderate expense and the fact that increased distance may slow work. The implementation of the distance principle is seen in the use of remote handling tools such as forceps, remote manipulators, robots and the proverbial 3-m pole. Other examples include the use of exclusion areas, such as evacuation after an accident (e.g., Chernobyl) or before a release (e.g., Nevada Test Site), and the use of signs, door interlocks, warning lights, and sirens. Another example is the design of large packages with the source in the center to limit surface dose rates.

(1996 August 9: see Addendum, p. 393)

Dispersal

The dispersal principle applies to radioactive materials in air, water, or soil. Dispersal is the way humankind has historically managed many waste problems, from human waste to wood smoke to automobile exhaust. A popular embodiment of this phrase is "The solution to pollution is dilution." At lower concentrations, intakes and ontakes are reduced. At lower concentrations, direct irradiation from a passing plume or bolus or a contaminated tailings pile is reduced. The commandment is *disperse it and dilute it*, or, technically, *minimize concentration, maximize dilution*.

Dispersal has the advantage, for environmental releases, of being inexpensive. Dispersal usually has the disadvantage of being irreversible. Its implementation through general (dilution) ventilation can be expensive for conditioned air spaces. Release of radioactive materials to sanitary sewer, which is permitted by regulations of the U.S. Nuclear Regulatory Commission, is a practical and safe way of disposing of many biomedical tracers. Dispersal is applied to management of radon progeny in both mines and in homes, and is applied in medical situations where patients may exhale radioactive gas. Note that the dispersal principle is antithetical to the source barrier principle of containment.

Source reduction

Source is used here in a generalized sense to mean a source of radiation or a mass of radioactive material.

Source reduction is the principle of reducing the amount of radioactive material being produced or used or reducing the amount of radiation being produced by a machine. Source reduction for radioactive materials is often a matter of good hygiene, leading to the commandment *use as little as possible*. Technically this becomes *minimize production and use of radiation and radioactive material*. There are several methods of source reduction that lead to subsidiary commandments: *clean it up and keep it clean*, *delay for decay*, and *do it now* to minimize ingrowth.

Costs of source reduction range from real savings to no cost to inexpensive to very expensive, depending on the implementation that is used. *A priori* source reduction, before a source is used or created, tends to be cheaper; *a posteriori* source reduction, after the source is created (such as in environmental cleanup), tends to be more expensive.

Simply using the smallest amount of radioactive material possible in an experiment or diagnosis is an example of source reduction. An example of source reduction by choosing the optimal non-radioactive materials is replacing valve components in nuclear power plants with materials containing less cobalt, resulting in a reduction of the amount of ^{60}Co produced. Chemical treatment and filtration of reactor coolant water to remove "crud" is another example of source reduction. Careful attention to beam alignment in accelerators minimizes both the production of stray radiation and the production of activation products. Contamination control through exhaust ventilation is an example of source reduction.

Two important methods of source reduction are management of decay time and management of ingrowth time. The technical commandment for the decay/ingrowth principle is to *delay (for decay) and do it now (for ingrowth)*, or, more technically, *optimize the timing by maximizing the decay time or minimizing the ingrowth time*.

For a radionuclide with a stable decay product, the dose rate diminishes exponentially with time. For some operations, simply delaying the action may result in significant dose reduction. Advantages of the "delay for decay" approach include that it may be very inexpensive if equipment is not needed, and in some cases, it may be the only choice (e.g., following a nuclear attack). Examples of the delay for decay principle include waiting to enter an accelerator target room until short-lived activation products have decayed, waiting to handle spent nuclear fuel until it has "cooled off," or staying in a fallout shelter until dose rates have diminished sufficiently. Another example is storing contaminated food for decay, a procedure that can be very effective for short-lived materials like 8.04-d ^{131}I . Sadly, this procedure was neglected after Chernobyl. For example, hay or grain can be stored for many half-lives; milk can be made into powdered milk, cheese, yoghurt, or ice cream; and grapes can be made into frozen concentrate or wine for storage. Disadvantages of delaying for decay include the

fact that it may be expensive if equipment is taken out of service for extended time (e.g., an expensive laboratory fraction collector contaminated with ^{125}I); or it may take a long time (e.g., weapons test fallout at Eniwetak or reactor accident fallout at Chernobyl). Implementation of “delay for decay” is fairly straightforward. Wait for radionuclides to decay; go away (use “distance”) and come back later; hold short-lived radioactive waste for decay, then dispose of it when it is less radioactive.

Managing ingrowth is just as important in many radiological protection situations. In particular, in the fuel fabrication business, $^{234\text{m}}\text{Pa}$ ingrowth in ^{238}U is a real concern that is managed by prompt processing of purified uranium, leaving the 24.1-d $^{234\text{m}}\text{Th}$ and its decay product, $^{234\text{m}}\text{Pa}$, in the “heel.” In uranium mining, ingrowth of radon progeny is minimized by vigorous ventilation, that is, removing the radon-laden air from the mine before the short-lived decay products grow in. In the ^{232}Th breeder fuel cycle, handling of the bred fuel is done promptly to minimize photon dose rates. Prompt handling of 28.6-y ^{90}Sr minimizes hazards from 64.1-h ^{90}Y . Finally, 432-y ^{241}Am grows in to 14.4-y ^{241}Pu , resulting in increasing photon dose rates.

Criticality safety is an important aspect of source reduction. Prevention of accidental criticality has become a radiation protection specialty largely outside of health physics.

Finally, any actions taken to prevent the use of nuclear weapons in anger are actions taken for source reduction for purposes of radiation protection. Thus nonproliferation activities and diplomacy, and activities to support these, are ultimately acts of radiation protection.

Source barrier

- *Barrier* is used here in a generalized sense to mean something that stops or slows a flow of matter or energy. In general there are two kinds of barriers: those that keep something in, and those that keep something out. The biological shield around a nuclear reactor is an example of the first kind of barrier, while a “graded” shield (with higher atomic number elements on the outside, diminishing to lower atomic number elements nearest the detector) in which a sensitive detector is housed is an example of the second kind of barrier. Filters can be used as either kind of barrier, such as filters to reduce releases and filters to reduce inhalation. The source barrier principle and its commandment, *keep it in*, are treated separately from the personal barrier principle and its commandment, *keep it out*, because they represent radically different approaches to the use of barriers.

Placing some kind of barrier between a source and the rest of the world is often called an “engineered control,” although that term includes more than barriers. For radiation sources such as x-ray machines and photon-emitting radionuclides, a barrier that attenuates the radiation is called a shield. For radionuclide sources, a barrier that prevents dispersal of the radioactive material may be a container, a filter, or an alternative chemical or physical form for the material.

It should be noted that at sufficiently great distances, even air is a very effective shield. For example, prompt radiation from a nuclear detonation is strongly attenuated by air at distances of several kilometers: 8 km of air at standard temperature and pressure has the same density-thickness (namely, $10,330 \text{ kg m}^{-2}$) as the earth’s atmosphere at sea level or 0.91 m of lead. Substantially shorter distances are effective for beta-emitting sources: the range of 1 MeV electrons is only about 4 m in air.

For the limitation of external irradiation, the *keep it in* commandment becomes *maximize absorption of the radiation from the source (shield the source)*. For the limitation of internal irradiation and skin contamination, the commandment becomes *minimize release of material (contain and confine the material)*. In a sense, shielding is containing radiation, while containment is containing radioactive material. Both methods are “keeping it in.”

The advantages of applications of the source barrier principle are primarily that they require no action on the part of the person being protected. Many radiation sources can be made intrinsically safe under normal or even under accident conditions. The dose reduction available by the use of shielding and containment is virtually unlimited. The disadvantages of the source barrier principle include substantial expense, reduced flexibility (e.g., thick shields to work around, remote manipulators to work through shields, shielding may have to be dismantled for servicing and must be checked on reassembly), and increased weight.

Implementation of the source barrier principle for external irradiation must be considered at the time of construction for activities such as radiology because retrofitting expenses can be astronomical. Shielding a source is usually cheaper and lighter than shielding a person (lead aprons). Examples include syringe shields in nuclear medicine (which implement both distance and shielding). Solid shields for photons are commonly made of lead, iron, concrete, earth, tungsten, depleted uranium, and leaded glass. Liquid shields for photons include water, mercury, and bromide solution. The disadvantage of liquid shields is the possibility of leaking. Solid shields for fast neutrons are usually proton-rich materials, e.g., polyethylene and paraffin, while thermal neutron absorbers include boron, cadmium, and indium. The most common liquid shield for neutrons is water. Electrons are best shielded with low atomic number materials to minimize bremsstrahlung. Shields are generally not required for alpha-emitting radionuclides. Filtration of an x-ray beam to harden it (i.e., eliminate the soft, non-penetrating component) is a special use of a source barrier; this is typically done with aluminum filters for diagnostic x rays and with a multi-layer, multi-element filter (called a “Thoraeus filter” after its inventor) for orthovoltage x rays.

Shielding can be deliberately incomplete to permit a beam of radiation to exit a source, such as in an industrial radiography device, thickness gauge, x-ray fluorescence analyzer, diagnostic x-ray machine, or teletherapy machine. In many of these cases, limitation of beam size

through collimation is an important application of the source barrier principle.

Implementation of the source barrier principle for the control of intakes and "ontakes" (skin contamination) of radioactive material usually involves engineering controls to concentrate and contain the radioactivity. This is the preferred method of control, as in industrial hygiene, rather than the personal barrier approach. Often primary and secondary containers, or even a multiplicity of containers, are used. Work compartments such as hot cells, glove boxes, and fume hoods are used. Another kind of source barrier is effluent treatment, such as air and water filtration, although these barriers are often used to regain control of materials that have been dispersed in a process or workplace. Contamination control measures such as bagging contaminated items, covering clean surfaces, or covering contaminated surfaces are applications of source barriers.

Personal barrier

The personal barrier principle may be summarized by the commandment *keep it out*, as distinguished from the source barrier principle of *keep it in*. This principle involves isolating the person from the radiation or radioactive material by use of a personal barrier. Protecting the individual from external radiation fields is done through the use of personal protective equipment (PPE) such as lead aprons, gloves, thyroid shields, and thick glasses. Protecting the individual from intakes and ontakes involves the use of PPE in the form of respiratory protection and protective clothing (PCs). The personal barrier approach is a method of last resort. Advantages include the ability to work in areas that would otherwise be unacceptable from a radiological point of view. Disadvantages include expense; discomfort due to heat stress and weight; restricted vision, movement, and communication; and for PCs, the generation of contaminated clothing that must be cleaned or discarded as radioactive waste. For example, the use of cumbersome lead gloves and lead aprons in radiology makes long hours of work tedious and may lead to back strain or injury.

Decorporation

The decorporation principle is limited to actions taken following intakes or ontakes of radioactive materials, since there is no way of removing from the body energy deposited by ionizing radiation. Decorporation is the removal of radioactive material from the interior or surface of the body, or the blocking of uptakes from systemic circulation by specific tissues or organs. The decorporation commandment is *get it out or off of you*, or, technically, *enhance removal or minimize uptake of materials from the body after intake or ontake*. Decorporation may range from simple cleanup to procedures performed only by physicians.

The removal of radioactivity from a contaminated person may be accomplished using decontamination methods such as washing or debridement (cleaning of a

wound by removal of damaged or contaminated tissue); purging or removal (e.g., with DTPA, a chelating agent; administering Prussian blue for cesium; or by forcing fluid intakes for $^3\text{H}_2\text{O}$); blocking tissue uptake by competitive mass action (e.g., the administration of potassium iodide as KI or Lugol's solution); or by surgery (excision).

Effect mitigation

Although not often considered by most practicing health physicists, mitigation of the effects of radiation, applied either before or after the ionizing energy has been deposited, is not fantasy. Effect mitigation does not include decorporation, which reduces the dose, but rather includes reducing the effect of a given individual dose or collective dose. An antidote for radiation exposure is not known to exist, and is unlikely to be found given the current state of understanding. However, there are several agents that can alter the effects of a given dose of radiation. Effect mitigators include free-radical scavengers such as vitamin E (α -tocopherol) and superoxide dismutase, and agents that reduce oxidative damage. Any agent that induces DNA repair mechanisms can also mitigate effects. The use of a small "priming dose" of radiation the day before a large dose significantly reduces the effect of the subsequent challenge dose in some animal species; this is known as "adaptive response" (UNSCEAR 1994). For non-human systems, there are mitigating effects of low temperatures, dryness (e.g., the radioresistance of spores and cockroaches), and anoxic conditions (e.g., in a poorly perfused tumor).

Effect mitigation can be achieved by clever consideration of dose-response relationships for individuals of similar and differing characteristics and of dose-rate effects. For a job that will result in a collective dose of 10 Sv, a radiation protection plan that spreads the collective dose among 1,000 people, each of whom receives 10 mSv, will result in less harm than a plan that spreads the dose among one to ten people, many of whom may suffer from acute, deterministic effects, perhaps including death. A similar benefit, that is, avoidance of acute effects, may be obtained by spreading the dose out over time to allow for repair, a well-established practice in radiation therapy. Although forbidden by laws promoting equal access to the workplace, using men instead of women for a given job reduces cancer risk because of women's 20% to 30% higher risk of cancer and greater loss of life expectancy for a given dose (National Research Council 1990, Table 4-2). And, finally, a lower expectation of harm will result from a radiation protection plan that causes a given collective dose in an older rather than in a younger population or to persons who will not be future parents rather than to persons who will be future parents.

Optimal technology

The commandment is *choose the best technology*, or, technically speaking, *maximize the risk-benefit-cost figure of merit*. Choosing the optimal technology may

mean using an ionizing radiation technology that produces a lower dose, or modifying an existing one so that it produces a lower dose (as limited by cost constraints). In some cases, choosing an optimal technology may mean using a technology that does not involve ionizing radiation. There are numerous examples of non-radiation technologies replacing radiation technologies:

- shoe-fitting fluoroscopes have been replaced by mechanical shoe-size gauges;
- pelvimetry, the practice of x-raying expectant mothers before birth to head off consequences of breech birth, has been replaced with diagnostic ultrasound;
- radioimmunoassay (RIA) has been replaced in some cases by an immunochemical assay called *enzyme linked immunosorbent assay* (ELISA) or fluorescence immunoassay (FIA);
- alternatives to nuclear fission or fusion for generating electricity or propelling ships (the "no nukes" option);
- alternatives to nuclear weapons for destroying an enemy, such as chemical, biological, or fuel-air weapons; and
- thorostrast, a contrast agent containing radioactive thorium, has been replaced by non-radioactive agents.

Other examples of choosing the optimal technology simply involve causing less dose:

- using ^{123}I ($T_{1/2} = 13$ h) rather than ^{131}I ($T_{1/2} = 8.04$ d), or using other radionuclides such as $^{99\text{m}}\text{Tc}$ where ^{131}I had been used; and
- using the fastest film-screen combination or other imaging modality that is consistent with the diagnostic information needed.

In some cases, using optimal technology may mean optimizing the existing technology, such as using good quality control on an x-ray film processor so that the maximum diagnostic information is obtained for a given dose.

Limitation of other exposures

This principle involves limiting exposures to other agents that may work in concert with ionizing radiation, such as genotoxic agents or those that may cause initiation, promotion, or progression of tumors. The commandment is *don't compound risks*, which includes the very important specific commandment *don't smoke*.

Under a *relative risk model* of carcinogenesis, one can limit numbers of excess cancers caused by radiation

by limiting the underlying risk as well. The lower the "background" cancer rate, the lower the radiogenic cancer rate for a constant relative risk. For example, if cigarette smoking causes 85% of lung cancers, then under a relative risk model smoking causes 85% of radiogenic lung cancers as well (Puskin and Nelson 1989).

CONCLUSIONS

"Time, distance, and shielding," the time-tested "basic" principles of radiation protection, are still as true as ever. But a view of all of the activities that are undertaken for purposes of radiation protection leads to the conclusion that the list of principles needs to be extended to ten. Specific "commandments," or actions, are also stated to indicate how to implement the principles. Each of these commandments is given in both a familiar and a technical form. And, as always, the application of the principles and commandments must be based on knowledge of the radiological conditions to be managed.

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REFERENCES

- National Research Council. Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V). Washington, DC: National Academy Press; 1990.
- Puskin, J. S.; Nelson, C. B. EPA's perspective on risks from residential radon exposure. *J. Air Pollut. Control Assoc.* 39:915-920; 1989.
- Strom, D. J. The *four* principles of external radiation protection: time, distance, shielding, and decay. *Health Phys.* 54:353-354; 1988.
- United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, effects, and risks of ionizing radiation. UNSCEAR's 1994 Report to the General Assembly, with Scientific Annexes. New York: United Nations; 1994.



Addendum to

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One additional commandment, "Stay upwind," should be listed under the "Distance" principle. This commandment applies to everything from a broken arrow incident (e.g., a nuclear weapon that has been damaged where the high explosive has detonated but there has been little or no fission or fusion, and there's a column of plutonium-laden smoke that one shouldn't breathe) to a person standing in front of a fume hood doing a protein iodination.