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ABSTRACT

This booklet is one in a series of instructional aids designed for use by elementary and secondary school science teachers. The various units and forms of radioactive materials used by teachers are first considered. Then, the quantities of radioisotopes that a person may possess without a license from the Atomic Energy Commission (AEC) are discussed, including a list of radioisotopes and allowable quantities. Procedure for applying to the AEC for a license to possess greater quantities is reviewed. Safety guidelines for instructors and students are considered, including safety in dispensing radioisotopes in the laboratory, laboratory precautions, decontamination, storage of radioactive materials, and waste disposal. (PR)

NATIONAL
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how to.

HANDLE RADIOISOTOPES SAFELY

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The first atomic reactor was built in 1942, but it was not until about 1946 that reactor-produced radioisotopes became commercially available. Since then, they have become a fundamental tool in almost every scientific discipline. Although it would take many books to enumerate the diverse applications of radioisotopes in research, education, and industry, it can be said very briefly that there are three basic ways in which they can be used: as tracers, as sources of power, and as sources of radiation.

In the field of education, use of the radioisotope has not kept pace with its versatility of use in research and industry. One reason for this lag is the need for more teacher training in the use and handling of radioisotopes. Apprehension can be cited as a second reason, apprehension resulting largely from the need for training.

By far the most important application of radioisotopes in research—whether it be in biology, chemistry, physics, or medicine—is their use as tracers. The quantity of a radioisotope used in a particular tracer application is extremely small, since one is merely interested in tagging a few molecules. Consequently, the quantities of radioisotopes normally used in research and for educational purposes are far safer to use than are many of the corrosive and flammable chemicals commonly found in the average high school chemistry laboratory.

UNITS AND FORMS OF RADIOACTIVE MATERIALS

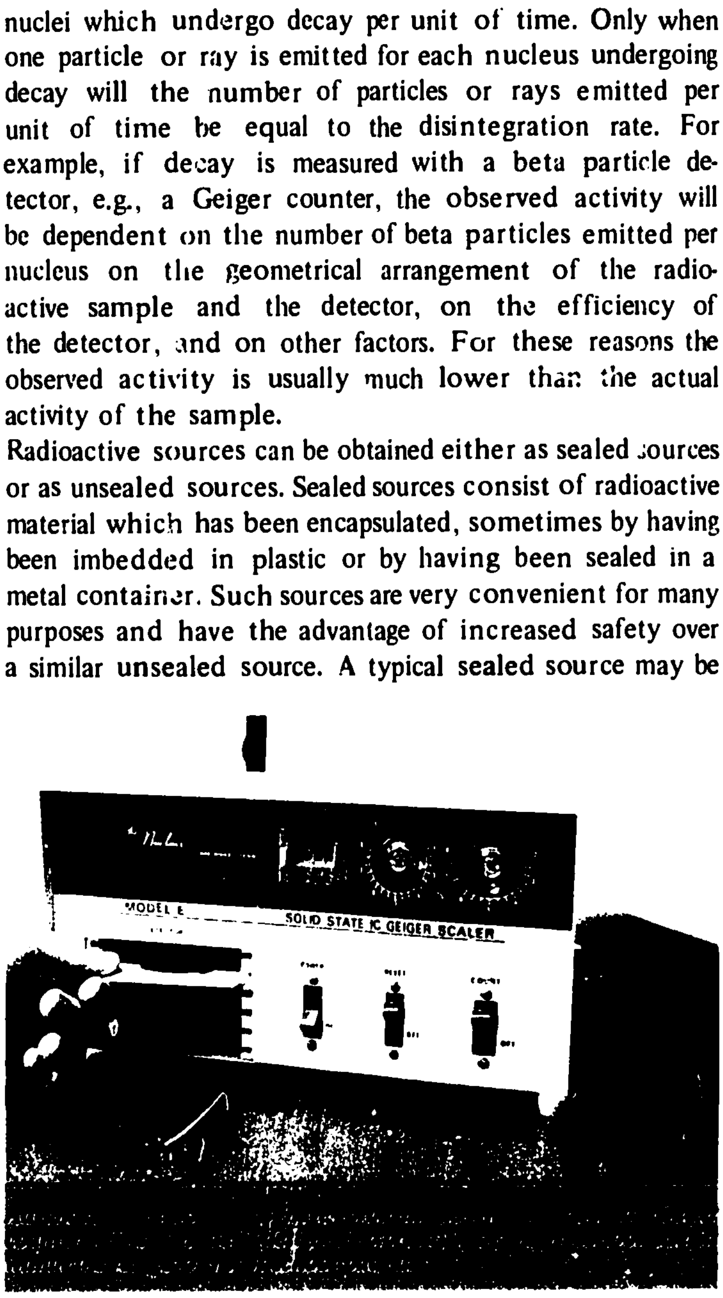
Radioactivity was originally defined in terms of the decay rate of one gram of the element radium, but the measurement of the exact decay rate of one gram of radium proved to be very difficult. It was *about* 3.7×10^{10} disintegrations per second (dps), so the unit of radioactivity, the curie (Ci), is now defined as that quantity of any radioactive material which undergoes radioactive decay at the rate of *exactly* 3.7×10^{10} dps. Because the curie is a relatively large unit, the millicurie and the microcurie are more frequently used in the educational laboratory. The relationships are:

1 curie (Ci) = 3.7×10^{10} dps
1 millicurie (mCi) = 3.7×10^{7} dps
1 microcurie (μCi) = 3.7×10^{4} dps

Microcurie quantities produce enough radiation to provide suitable counting rates yet pose minimal radiation hazards.

Note that the curie, millicurie, and microcurie units are a measure of the disintegration rate; that is, the number of nuclei which undergo decay per unit of time. Only when one particle or ray is emitted for each nucleus undergoing decay will the number of particles or rays emitted per unit of time be equal to the disintegration rate. For example, if decay is measured with a beta particle detector, e.g., a Geiger counter, the observed activity will be dependent on the number of beta particles emitted per nucleus on the geometrical arrangement of the radioactive sample and the detector, on the efficiency of the detector, and on other factors. For these reasons the observed activity is usually much lower than the actual activity of the sample.

Radioactive sources can be obtained either as sealed sources or as unsealed sources. Sealed sources consist of radioactive material which has been encapsulated, sometimes by having been imbedded in plastic or by having been sealed in a metal container. Such sources are very convenient for many purposes and have the advantage of increased safety over a similar unsealed source. A typical sealed source may be



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shaped as a disc and labeled with the name of the manufacturer, the date of manufacture or calibration, and the identity of the isotope and its microcurie strength.

Typical unsealed sources are supplied as aqueous solutions of the radioactively tagged compound, or as a dry powder, depending upon the amount of chemical substance present and the use to which the sample is to be put. Some solutions have other chemicals added for specific purposes. For example, ^{32}P is frequently supplied as a solution of $Na_2H^{32}PO_4$ (dibasic sodium phosphate ^{32}P). If the solution contains $1 \mu Ci$ of ^{32}P, it can readily be calculated (as shown below) that the weight of $Na_2H^{32}PO_4$ in the solution is only 1.5×10^{-5} μg. Such small amounts of material are quickly adsorbed on the walls of the container. To prevent adsorption from solution, it is common practice to add a "carrier." In this instance a carrier of nonradioactive phosphate would be used, enough nonradioactive Na_2HPO_4, KH_2PO_4 (monobasic potassium phosphate), H_3PO_4 (ortho phosphoric acid), or other source of phosphate ion being added to the solution to increase the total concentration of phosphate to approximately 0.001 molar.

Additives are sometimes used to suppress the formation of undesirable chemical forms of the radioelement. Sodium sulfite (Na_2SO_3), for example, is sometimes added to solutions of radioactive iodide solutions to prevent oxidation of the radioactive iodide. In certain restrictive applications the facts about additives must be known for proper utilization of the radioactive material.

Specific activity of a sample is a measure of the radioactivity per unit quantity of mass of the substance. It was mentioned above that 1 μCi of $Na_2H^{32}PO_4$ weighs only 1.5×10^{-5} μg. This corresponds to a specific activity of 66 $mCi/\mu g$ or 66 Ci/mg ($1 \mu Ci / 1.5 \times 10^{-5} \mu g = 66 \times 10^3 \mu Ci/\mu g = 66\ mCi/\mu g = 66 \times 10^{-3}\ Ci/\mu g = 66$ Ci/mg). If 9 parts of nonradioactive Na_2HPO_4 are added to 1 part of $Na_2H^{32}PO_4$ so as to dilute the radioactivity of the compound tenfold, the specific activity would then be 6.6 $mCi/\mu g$. Specific activity is not, however, limited to the total activity per unit weight of the substance. It is also defined as the activity per unit mass of a pure radionuclide. Most tables of specific activity list the latter.

Radiological concentration of a sample is a measure of the radioactivity per unit volume of the solution. If the above 1 μCi of $Na_2H^{32}PO_4$ were contained in 10 ml of solution, the radiological concentration would be 0.1 $\mu Ci/ml$. Addition of nonradioactive Na_2HPO_4 would not change the radiological concentration. It would, however, increase the chemical concentration and at the same time decrease the specific activity.

LICENSE REQUIREMENTS

There are two types of licenses, general and specific. The Atomic Energy Commission permits individuals to possess and use certain small quantities of radioactive materials without having obtained a specific license. The quantities listed in Table 1 are available under such a general license. That is to say, without the need of filing any form or applying in any way, everyone is permitted to possess isotopes in

Calculation of Weight of $Na_2H^{32}PO_4$

Activity = $A = 1\ \mu Ci = 3.70 \times 10^4\ sec^{-1}$
Half-life of $^{32}P = t_{1/2} = (14.3d)(24h/d)(60m/h)(60sec/m) = 1.24 \times 10^6 sec$
Decay constant $\lambda = 0.693/t_{1/2} = 5.61 \times 10^{-7}\ sec^{-1}$
Atoms (in one μCi) of $^{32}P = N = A/\lambda = 3.70 \times 10^4 sec^{-1} / 5.61 \times 10^{-7} sec^{-1} = 6.59 \times 10^{10}$
Number of molecules of $Na_2H^{32}PO_4$ = number of atoms of $^{32}P = 6.59 \times 10^{10}$

$$\text{Weight of } Na_2H^{32}PO_4 = \frac{M.W.}{No.} \times N,$$

where M.W. = molecular weight of $Na_2H^{32}PO_4 = 143$
No. = Avogadro number = 6.023×10^{23} molecules/gram molecule

$$\text{Weight of } Na_2H^{32}PO_4 = \frac{143}{6.023 \times 10^{23}} \times 6.59 \times 10^{10} = 1.56 \times 10^{-11} g = 1.56 \times 10^{-5}\ \mu g$$

TABLE 1–SCHEDULE B

Quantities of Isotope Byproduct Material Allowable License-free for Individual Needs

Byproduct material	*Microcuries*
Antimony 122 (Sb 122)	100
Antimony 124 (Sb 124)	10
Antimony 125 (Sb 125)	10
Arsenic 73 (As 73)	100
Arsenic 74 (As 74)	10
Arsenic 76 (As 76)	10
Arsenic 77 (As 77)	100
Barium 131 (Ba 131)	10
Barium 140 (Ba 140)	10
Bismuth 210 (Bi 210)	1
Bromine 82 (Br 82)	10
Cadmium 109 (Cd 109)	10
Cadmium 115m (Cd 115m)	10
Cadmium 115 (Cd 115)	100
Calcium 45 (Ca 45)	10
Calcium 47 (Ca 47)	10
Carbon 14 (C 14)	100
Cerium 141 (Ce 141)	100
Cerium 143 (Ce 143)	100
Cerium 144 (Ce 144)	1
Cesium 131 (Cs 131)	1,000
Cesium 134m (Cs 134m)	100
Cesium 134 (Cs 134)	1
Cesium 135 (Cs 135)	10
Cesium 136 (Cs 136)	10
Cesium 137 (Cs 137)	10
Chlorine 36 (Cl 36)	10
Chlorine 38 (Cl 38)	10
Chromium 51 (Cr 51)	1,000
Cobalt 58m (Co 58m)	10
Cobalt 58 (Co 58)	10
Cobalt 60 (Co 60)	1
Copper 64 (Cu 64)	100
Dysprosium 165 (Dy 165)	10
Dysprosium 166 (Dy 166)	100
Erbium 169 (Er 169)	100
Erbium 171 (Er 171)	100
Europium 152 9.2 h (Eu 152 9.2 h)	100
Europium 152 13 yr (Eu 152 13 yr)	1
Europium 154 (Eu 154)	1
Europium 155 (Eu 155)	10
Fluorine 18 (F 18)	1,000
Gadolinium 153 (Gd 153)	10
Gadolinium 159 (Gd 159)	100
Gallium 72 (Ga 72)	10
Germanium 71 (Ge 71)	100
Gold 198 (Au 198)	100
Gold 199 (Au 199)	100
Hafnium 181 (Hf 181)	10
Holmium 166 (Ho 166)	100
Hydrogen 3 (H 3)	1,000
Indium 113m (In 113m)	100
Indium 114m (In 114m)	10
Indium 115m (In 115m)	100
Indium 115 (In 115)	10
Iodine 125 (I 125)	1
Iodine 126 (I 126)	1
Iodine 129 (I 129)	0.1
Iodine 131 (I 131)	1
Iodine 132 (I 132)	10
Iodine 133 (I 133)	1
Iodine 134 (I 134)	10
Iodine 135 (I 135)	10
Iridium 192 (Ir 192)	10
Iridium 194 (Ir 194)	100
Iron 55 (Fe 55)	100
Iron 59 (Fe 59)	10
Krypton 85 (Kr 85)	100
Krypton 87 (Kr 87)	10
Lanthanum 140 (La 140)	10
Lutetium 177 (Lu 177)	100
Manganese 52 (Mn 52)	10
Manganese 54 (Mn 54)	10
Manganese 56 (Mn 56)	10
Mercury 197m (Hg 197m)	100
Mercury 197 (Hg 197)	100
Mercury 203 (Hg 203)	10
Molybdenum 99 (Mo 99)	100
Neodymium 147 (Nd 147)	100
Neodymium 149 (Nd 149)	100
Nickel 59 (Ni 59)	100
Nickel 63 (Ni 63)	10
Nickel 65 (Ni 65)	100
Niobium 93m (Nb 93m)	10
Niobium 95 (Nb 95)	10
Niobium 97 (Nb 97)	10
Osmium 185 (Os 185)	10
Osmium 191m (Os 191m)	100
Osmium 191 (Os 191)	100
Osmium 193 (Os 193)	100
Palladium 103 (Pd 103)	100
Palladium 109 (Pd 109)	100
Phosphorus 32 (P 32)	10
Platinum 191 (Pt 191)	100
Platinum 193m (Pt 193m)	100
Platinum 193 (Pt 193)	100
Platinum 197m (Pt 197m)	100
Platinum 197 (Pt 197)	100
Polonium 210 (Po 210)	0.1
Potassium 42 (K 42)	10
Praseodymium 142 (Pr 142)	100
Praseodymium 143 (Pr 143)	100
Promethium 147 (Pm 147)	10
Promethium 149 (Pm 149)	10
Rhenium 186 (Re 186)	100
Rhenium 188 (Re 188)	100
Rhodium 103m (Rh 103m)	100
Rhodium 105 (Rh 105)	100
Rubidium 86 (Rb 86)	10
Rubidium 87 (Rb 87)	10
Ruthenium 97 (Ru 97)	100
Ruthenium 103 (Ru 103)	10
Ruthenium 105 (Ru 105)	10
Ruthenium 106 (Ru 106)	1
Samarium 151 (Sm 151)	10
Samarium 153 (Sm 153)	100
Scandium 46 (Sc 46)	10
Scandium 47 (Sc 47)	100
Scandium 48 (Sc 48)	10
Selenium 75 (Sc 75)	10
Silicon 31 (Si 31)	100
Silver 105 (Ag 105)	10
Silver 110m (Ag 110m)	1
Silver 111 (Ag 111)	100
Sodium 24 (Na 24)	10
Strontium 85 (Sr 85)	10
Strontium 89 (Sr 89)	1
Strontium 90 (Sr 90)	0.1
Strontium 91 (Sr 91)	10
Strontium 92 (Sr 92)	10
Sulphur 35 (S 35)	100
Tantalum 182 (Ta 182)	10
Technetium 96 (Tc 96)	10
Technetium 97m (Tc 97m)	100
Technetium 97 (Tc 97)	100
Technetium 99m (Tc 99m)	100
Technetium 99 (Tc 99)	10
Tellurium 125m (Te 125m)	10
Tellurium 127m (Te 127m)	10
Tellurium 127 (Te 127)	100
Tellurium 129m (Te 129m)	10
Tellurium 129 (Te 129)	100
Tellurium 131m (Te 131m)	10
Tellurium 132 (Te 132)	10
Terbium 160 (Tb 160)	10
Thallium 200 (Tl 200)	100
Thallium 201 (Tl 201)	100
Thallium 202 (Tl 202)	100
Thallium 204 (Tl 204)	10
Thulium 170 (Tm 170)	10
Thulium 171 (Tm 171)	10
Tin 113 (Sn 113)	10
Tin 125 (Sn 125)	10
Tungsten 181 (W 181)	10
Tungsten 185 (W 185)	10
Tungsten 187 (W 187)	100
Vanadium 48 (V 48)	10
Xenon 131m (Xe 131m)	1,000
Xenon 133 (Xe 133)	100
Xenon 135 (Xe 135)	100
Ytterbium 175 (Yb 175)	100
Yttrium 90 (Y 90)	10
Yttrium 91 (Y 91)	10
Yttrium 92 (Y 92)	100
Yttrium 93 (Y 93)	100
Zinc 65 (Zn 65)	10
Zinc 69m (Zn 69m)	100
Zinc 69 (Zn 69)	1,000
Zirconium 93 (Zr 93)	10
Zirconium 95 (Zr 95)	10
Zirconium 97 (Zr 97)	10
Any byproduct material not listed above other than alpha emitting byproduct material	0.1

quantities up to those listed in Table 1. Even *you* are generally licensed to possess isotopes in these quantities. That is why these quantities of isotopes are sometimes referred to as being "license-exempt" or "license-free" quantities. For convenience, the pertinent portion of the AEC regulations is excerpted: "...any person is exempt from the requirements for a [specific] license ... to the extent that such person receives, possesses, uses, transfers, owns, or acquires byproduct material in individual quantities each of which does not exceed the applicable quantity set forth in Section 30.71 Schedule B," Title 10 Code of Federal Regulations Part 30 (Table 1).

It is important to realize that the AEC regulations constitute a *possession* limit. There is no restriction on the number of such scheduled quantities that can be used in a year so long as the amount of an individual quantity does not exceed the limit set forth in Schedule B. If it is desired to possess an individual source greater than the quantity listed, it is necessary to possess a *specific license* for that isotope. Specific licenses are discussed in the next section.

Actually, on the high school level, specific licenses are not really necessary in about 9 out of 10 cases. Some school districts—especially the larger ones—designate one individual or laboratory to secure a specific license for economic reasons. Since 100 μCi of ^{32}P costs only a little more than 10 μCi, the specific licensee can then divide the higher activity down to the license-free level and distribute these smaller quantities among other laboratories within the district. Thus, the cost is greatly reduced, but possession of a specific license entails paper work and record keeping on the part of the instructor.

Over the past few years a number of states have entered into agreements with the AEC wherein the AEC relinquishes jurisdiction over radioactive materials to the state. These states, sometimes called "Agreement States," have regulations similar to those of the AEC. In some cases the quantities of certain license-free materials may differ from those in the AEC schedules. Individuals living in an agreement state should write for a copy of the state regulations. These are normally available from the state department of public health.

OBTAINING AN AEC SPECIFIC LICENSE

Although tracer-level work with radioisotopes can usually be performed with generally licensed or "license-free" quantities, those who teach many students, who introduce a greater variety of experimental work into their teaching, or who for reasons of economy wish to order larger quantities of radioisotopes, may find possession of an AEC specific license to be desirable. Application for a specific license should be made on Form AEC-313 which can be obtained by writing to the U. S. Atomic Energy Commission, Washington, D. C. 20545 Attention: Division of Materials Licensing.

When reviewing applications for specific licenses, the AEC considers each individually. The Commission will take into consideration such factors as prior experience of the individual user and/or his training, the quantity and properties of the particular isotope desired, its intended use, the instrumentation available, safety measures to be taken, and plans for disposal of the isotopes. The primary objective is to assure that the radioactive materials will be used with safety to both the user and the community.

Individuals who have received training in the use of radioisotopes through attendance at AEC-NSF sponsored institutes or another equivalent training program should have little or no difficulty in obtaining a specific license for a few millicuries of short-lived materials such as ^{32}P, provided the topics mentioned in the previous paragraph have been properly considered. Instrumentation, for example, should include a scaler with a thin end-window G-M tube, a ratemeter of at least the Civil Defense V 700 type, and Civil Defense type dosimeters.

Similarly, individuals who have had a few years' experience with license-exempt quantities should be able to obtain a specific license for a few millicuries of ^{32}P assuming other requirements of instrumentation and program are met. It is necessary to convince the licensing agency of the AEC or agreement state that you are capable of handling the desired isotope safely.

To work with the larger quantities of isotopes usually possessed under specific licensure from the AEC, it is normally advisable to subscribe to a film badge service. Although it is not likely that the dose received by the teacher would exceed the limits in Table 2, or that the dose to students under the age of 18 should exceed 5 percent of the values listed, a personnel monitoring program such as a film badge service must be used if these levels are anticipated.

TABLE 2—LIMITS OF RADIATION DOSE

Area of Body	*Rems per Calendar Quarter**
1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1¼
2. Hands and forearms; feet and ankles	18¾
3. Skin of whole body	7½

*(For individuals under 18 years of age the exposure limit is 10 percent of the value given.)

Those who possess a specific license must also keep certain records. These include the date and quantity of radioactive material received, the supplier, and its disposition or transfer. A bound notebook is ideal for this purpose. If dosimeters are worn, a record should be kept of any radiation exposure in another bound notebook.

SAFETY GUIDELINES

The instructor should prepare a set of radiation safety rules applicable to his particular institution. The "USAEC Guide for Drafting Radiation Safety Instructions for Laboratory Use of Radioisotopes" should be very helpful in this respect. Copies of the safety rules should be posted in conspicuous locations and distributed to individuals new to the laboratory.

Three methods of protecting against external radiation are time, distance, and shielding. Reducing an individual's working time is the simplest way to limit his exposure. In fields of constant radiation intensity, the dose received by an individual is proportional to the length of time he remains in that area. For sources that are concentrated in small areas, radiation intensity varies as the inverse square of the distance from that source. To illustrate, if an individual doubled his distance from the source, his exposure would be reduced to one-fourth; tripling the distance would effect a reduction to one-ninth the original exposure. Finally, the purpose of shielding is to attenuate radiation by means of absorption. Individuals may work for longer periods of time and closer to radiation sources when shielding is interposed between them and the source.

When dispensing radioisotopes to students, one must know the quantity students may be expected to handle with relative safety. The quantity will depend upon the radiological half-life, type, and energy of the radiation emitted, and the biological half-life which is determined

USAEC GUIDE FOR DRAFTING RADIATION SAFETY INSTRUCTIONS FOR LABORATORY USE OF RADIOISOTOPES*

1. Outline control procedures for obtaining permission to use radioactive materials at the institution; give limitations on quantity to be handled per student or allowed per experiment, etc.
2. Explain what laboratory apparel to wear and what equipment to use.
3. Prescribe limitations and conditions relative to handling liquid or loose radioactive materials and what laboratory equipment to use in working with them. For example, explain when materials and what operations should be confined to radiochemical fume hoods or gloveboxes. Explain what shielding or remote handling equipment is to be used when hard beta and/or gamma emitting materials are handled.
4. Outline routine survey and monitoring procedures to be followed for contamination control.
5. Emergency procedures should include instructions concerning spills, fires, release of material, and/or accidental contamination of personnel. Outline decontamination procedures to use and whom to contact in case of emergencies.
6. Give instructions concerning movement of materials between rooms, halls, or in corridors, if applicable.
7. Explain requirements for storage of materials, labeling of containers, and identification of areas where radioactive materials are used. Explain where and how contaminated articles and glassware are to be handled and stored.
8. Name personnel monitoring devices to use, where to obtain them, and give instructions on recording exposure results.
9. Indicate waste disposal procedures to follow and give limitations for disposal of liquid or solid wastes and procedures to use for waste storage. If program involves experiments in animals, outline instructions on cleaning animal quarters and handling animal excreta and carcasses for disposal.
10. Explain what records are to be kept on materials used and disposed.

*(From USAEC communications to applicants)

RULES FOR LABORATORY WORK*

1. Eating, drinking, and the use of cosmetics in the laboratory are not permitted.
2. Pipetting or the performance of any similar operation should not be done by mouth suction. Special suction devices are available for use with pipettes.
3. Before a worker leaves the laboratories, the hands should be washed first, then checked with a beta-gamma survey meter. Contamination remaining after thorough washing should be reported.
4. If, in the course of work, personal contamination is suspected, a survey with a suitable instrument should be made immediately. This should be followed by the required cleansing and a further survey. Routine precautionary surveys should be made at intervals.
5. Rubber gloves must be worn at all times while in the laboratory.
6. The dosimeter or film badge should be worn if required.
7. Active liquid wastes should be poured into the labeled beakers provided. They should *never* be poured into a standard drain. The *student* should not discard radioactive materials into a standard drain because:
    a. Records must be kept of disposed materials to assure compliance with the regulations.
    b. A special drain should be set aside for the disposal of radioactive waste. The waste sink selected should have minimal exposed drainpipe to minimize radiation hazards from potential buildup of radioactive material in the pipe. A specific sink should also be used to avoid unnecessary contamination of other sinks and waste lines.
8. Active solid wastes and contaminated materials should be placed in trash cans labeled "contaminated."
9. All wounds, spills, and other emergencies should be reported to the instructor immediately.
10. Good housekeeping is encouraged at all times. Spillage should be prevented, but in the event of such an accident the following procedure should be followed:
    a. The liquid should be blotted up. (Wear rubber gloves.)
    b. All disposable materials contaminated by the spill and the cleaning process should be placed in a "contaminated" can.
    c. The area of the spill and the type of activity (e.g., ^{131}I) should be clearly marked.
11. In general, active materials and contaminated materials are to be retained within the radioisotope laboratory and at specific points within the laboratory.
12. Before leaving the laboratory, be sure all written records, if required, have been completed.

*(These laboratory regulations have been adapted from those in use at the Oak Ridge Institute of Nuclear Studies.)

by the chemical properties of the material. These are some of the factors considered in arriving at the exempt quantities listed in Table 1. It is therefore convenient to use Table 1 as a guide. We see, for example, that the limit for strontium 90 is 0.1 μCi. Accordingly, if strontium 90 is used, it would be wise to dispense it in the form of small prepared sources rather than as a solution. On the other hand, 10 μCi of phosphorus 32 can be used with approximately equal safety. When isotopes are obtained in millicurie amounts, they should be handled only by the instructor, even though not required by regulation. Only "license-exempt" quantities as indicated in Table 1 should be issued for student use.

Many experiments in radioactivity can be performed with a small number of different radioactive sources.

INSTRUCTOR TRAINING IN THE USE OF RADIOISOTOPES

For about two decades the Atomic Energy Commission, in cooperation with the National Science Foundation, has provided financial aid and technical assistance to encourage training in radioisotope methodology for both college and high school instructors. NSF-AEC Institutes in the nuclear sciences have included summer institutes, inservice institutes, and academic year institutes. Although AEC and NSF support has been very substantial, only about 6,000 of the 100,000 science teachers in the country have been privileged to receive this training. Many individuals have been trained in similar courses as part of graduate and undergraduate science programs.

For the individual who has not received any formal radioisotope training, self-training is another possible alternative. The Atomic Energy Commission, Civil Defense, commercial nuclear science companies, and textbook companies all have a variety of materials available for self-training in radioisotope methodology. Of course, such sources cannot provide any laboratory program, but an interested instructor may obtain acceptable training outside formal channels.

DISPENSING RADIOISOTOPES IN THE LABORATORY

As with all other forms of matter, radioisotopes may be encountered in solid, liquid, or gaseous forms. Submicrocurie sealed sources may be handled safely with fingers, forceps, or other devices used for manipulating small objects.

Radioactive material in gaseous form is rarely dispensed but may be encountered as a product of a chemical reaction. Normal procedures for handling toxic or corrosive gases such as chlorine, carbon monoxide, etc., will suffice for radioactive gases such as tritium and ^{14}C-carbon dioxide in most cases. The two essential factors in handling radioactive gases are: containment of the gas itself (through the use of hoods, gloveboxes, and sealed systems) and a continuous thorough monitoring of the laboratory atmosphere by means of monitoring devices especially adapted for the purpose. Under most conditions, a properly operating hood will be sufficient. Handling of radioactive gases is normally avoided in educational courses of the introductory type, except for radiocarbon dioxide.

Radioactive materials are most often used in the form of a liquid solution because of the ease of handling and ease of accurately measuring micro volumes rather than weights of material on the microgram level.

Small volumes of radioactive solutions may be handled in the same manner as semimicro quantities of ordinary reagents. Ordinary medicine droppers may be used when only an approximate volume of radioactive liquid is to be dispensed; most droppers of this type yield about 20 drops per ml. The extremely low cost of medicine droppers makes them especially appealing since they may be considered a throw-away item.

For more accurate dispensing of semimicro quantities of radioactive liquids, ordinary laboratory pipettes of the Mohr type may be used in conjunction with an ingenious device called a Propipetter. By means of a clever system of ball valves, radioactive liquids may be drawn up into the pipette and then later expelled, thus obviating the practice of mouth suction. Since mouth suction with pipettes is a hazardous practice with most "ordinary" laboratory chemicals and biologicals, the Propipetter will be found in most chemical and biological laboratories as usual equipment.

Workers familiar with micro or semimicro techniques should have no difficulty handling volumes of radioactive liquids of below one ml volume. Special thin bore pipettes, to hold volumes of liquid on the microliter level, are used in conjunction with micropipette controls. One microliter (one lambda, 1 λ) is one millionth of a liter or one thousandth of a ml; pipettes are available in sizes from 500 λ down to 1 λ. The micropipette control is a small metal cylinder of glass or plastic in which the volume of air admitted is regulated with a screw-thread wheel at its top. This volume of air thus controls the liquid level in the attached micropipette. The whole apparatus may be easily handled with one hand. See the illustration on the next page.

To measure approximate volumes of solutions, ordinary 5mm stirring rods may be used in place of micropipettes. The drop of liquid dispensed from the end of a stirring rod will be in the neighborhood of 25 λ.

It is good practice to handle radioactive liquids over a tray lined with absorbent paper so contamination of the workbench will be minimized in case of a spill. Some workers also prefer to protect the workbench underneath with the same paper. The usual protective paper consists of two layers; the top layer is absorbent and the bottom layer is water repellent. An aluminum or plastic cafeteria tray lined with newspaper over waxed paper will also make an effective absorbent lining in case of spills.

The use of absorbent paper makes decontamination after a spill a relatively simple matter; the wet absorbent paper is readily discarded into the waste container. Tissue, paper towels, photographic blotter paper, and newspapers are excellent absorbent papers either for the lining or for wiping up a spill.

It is good practice, and also mandatory in some laboratories, to wear thin rubber surgeon's gloves while handling radioactive liquids. The gloves should be of the proper size, and talcum powder should be added to the inside to suppress perspiration effects and for more comfortable wearing. Even with persons unfamiliar with the wearing of these gloves, manual dexterity returns in a few minutes. Some instructors prefer to use the disposable type of thin polyethylene glove. These gloves are worn once and then thrown away. The less expensive would be the more permanent surgeon's glove.

Gloves should always be worn when long-lived radioisotopes or alpha emitters are handled, or when the worker has cuts on the hands. It is really not necessary, but good practice, to wear rubber gloves when handling even license-exempt quantities of isotopes.

Rubber gloves are normally worn for preparative work. They are rarely used when counting samples in order to prevent contamination of counting equipment.

After the lab period, the gloves should be monitored for contamination by a lab partner *while they are still on the hands*. If radioactivity is observed, the gloves should be washed *while still on the hands*. A good scrubbing with an abrasive cleanser is usually sufficient decontamination for a gloved hand.

For counting purposes, small quantities of radioactive liquid are usually added to a small shallow cup called a planchet. The planchets are dried under a heat lamp. To retard flaking or volatilization of the radioactive material the planchets may be sprayed with a transparent lacquer such as Krylon which can be purchased in a convenient spray can. Planchets come in many shapes, sizes, and different materials, but all may be handled safely and easily with either special planchet forceps or ordinary laboratory forceps.

Certain other safeguards should be exercised when radioactive materials are used in experiments involving animals.

In many experiments designed to follow the pathways of certain elements in animals, such as the uptake of ^{32}P by rats, mice, or frogs, the radioactive material is injected directly into the animal. The creatures must be adequately anesthetized prior to injection, for an animal resisting injection can sometimes cause contamination of nearby areas. Injections should take place over the paper-lined trays mentioned earlier. Disposable syringes are best for this purpose since they may be discarded with other radioactive waste.

Once the animals have been fed or injected with radioisotopes, they should be kept in a secure, labeled cage which has been lined with absorbent paper to retain any radioactive excreta. All such paper linings and excreta may be discarded with other radioactive waste in the designated waste disposal receptacle. Rubber gloves should be used when handling the animals or their waste.

Animals' carcasses and organs, and plants, are conveniently discarded in small bottles with the other radioactive waste. Small carcasses should be placed in polyethylene sandwich bags before insertion into the bottle. Bottles should be securely closed and properly marked.

Plants being grown in atmospheres containing radiocarbon as $^{14}CO_2$ in closed systems should be kept in hoods in the event of leakage from the system.

THE RADIOLOGICAL HEALTH PROGRAM

The old adage, "An ounce of prevention is worth a pound of cure," is never more true than when applied to the handling of radioactive materials. When good laboratory practices and common sense are followed, there should be no cause for any concern over radiological health of the laboratory workers.

Although license-free quantities of radioactive materials present a minimal hazard, student workers should be taught the fundamentals of radiation safety practices. Any such rules should be rigidly enforced. They should also be mimeographed for students and posted in a conspicuous place as a reminder.

The most widely used monitoring device is the film badge, which is worn by persons in laboratories where one may be exposed to radioactive materials. For experimentation with only license-exempt quantities of radioactive material, even a film badge is not needed. If such experimentation takes place over a period of an entire school year, it is advisable to have a monthly film badge service for the instructor and one or two of the students. The film badge records should be kept in a permanent file for any future use. This small reassurance has a great effect on the morale of the students.

When quantities of radioactive material are used under an AEC specific license, special precautions are necessary. If an individual under 18 years of age is likely to receive a dose of radiation in excess of 62.5 mrem per calendar quarter (5 percent of 1¼ rems), appropriate personnel monitoring equipment must be supplied. The film badge service is highly recommended for this purpose. Whenever an unusual dose shows up on a film badge, the subscriber is notified immediately by the company with either a long-distance call or a telegram. The film badge record is also good insurance in the event of a radiation-damage suit.

Some instructors also prefer the students to wear pocket dosimeters as well as or in place of the film badge. With license-free sources, no radiation exposure should ever be recorded on these devices because of the extremely small amount of radiation encountered. In almost every case, any movement of the reticle fiber on a dosimeter is nothing more than leakage of the charge, a perfectly natural occurrence considering their construction and sensitivity. The workers are required to read the dosimeters before and after the laboratory period and record any dose rate in a bound notebook or similar record. Although this procedure is unnecessary with license-free materials, the good safety habits acquired are of great value if the student goes on later to work with higher activities.

Avoid ingestion or inhalation of radioisotopes. Eating, drinking, smoking, chewing gum, or applying cosmetics while engaged in laboratory activities should be forbidden. Radioactive contamination that may be deposited on hands or gloves can be transferred to food, etc. Internally deposited radioisotopes can locate in specific body organs. Cells in intimate contact with radioactive particles will receive all of the emitted energy, resulting in cellular damage.

A portable battery-operated ratemeter should be available for personal monitoring near the laboratory door. Before the worker leaves the laboratory, the work area, the hands, and the clothing should be monitored for possible contamination. The instrument should be set for its lowest scale reading with the time constant (if any) set at "SHORT," and the probe should be moved slowly over the suspected area of table or body without actually touching it. Any appreciable count over background should be interpreted as possible contamination, and decontamination procedures should be instituted immediately. If average background is about 30 cpm, a count of 50 or 60 cpm would be evidence of slight contamination.

The detector used for monitoring should match the radiation emitted by the suspected contaminant. Geiger counters will not detect all types of radiation, nor will they detect radiation of certain energies. For example, the common CD V 700 instrument supplied to most public high schools by Civil Defense will not detect alpha particles or soft (weak) beta radiation, because the tube thickness is so great the particles cannot penetrate the tube wall. The weak beta radiation emitted by carbon 14 (0.154 MeV) and sulfur 35 (0.167 MeV) can be detected with a thin end-window Geiger tube of 1.4 - 3.0 mg/cm^2 density thickness but not with the thicker side-window Geiger tube of 30 mg/cm^2 density thickness, as found on the V 700 apparatus. Such monitoring procedures seldom reveal any contamination if good housekeeping is the rule, except for accidental spills.

The instructor's attitude toward the handling of radioisotopes will be mirrored in his pupils. If the instructor has a devil-may-care, lackadaisical attitude, the students will soon be acting in the same way. The instructor should strike a happy medium between a devil-may-care and a fanatical attitude. Respect, not fear, is a much more beneficial attitude to assume in the handling of radioactive materials.

EXPERIMENTATION WITH RADIOISOTOPES BY MINORS

All individuals are constantly exposed to radiation and have been since the birth of mankind. While the average radiation dose from natural sources in our environment is about 150 mrem per year, people living at high altitudes, e.g., Denver, Colorado, receive as much as 200 mrem per year. When compared with the allowed dose of 125 mrem per calendar quarter (500 mrem per year), it is seen that the AEC has said, in effect, that no minor shall be exposed to more radiation from artificial sources than he normally receives from his environment.

Studies of film badge records of educational radioisotope laboratories have shown that almost all such laboratory workers receive a radiation dose of essentially *zero* from the handling of radioactive materials. This statement is

Approximate volumes of radioactive liquids can be dispensed by means of an ordinary stirring rod.

true even when the activities handled are more than 100 times the license-free levels normally used on the high school level. Thus, radiation danger from handling license-free quantities of radioisotopes is negligible when the common sense guidelines of the AEC are followed.

THE RADIOISOTOPE WORK AREA

Care should be exercised in the selection of a radioisotope area, whether the laboratory involved is large or small. Relatively expensive counting equipment should be kept away from the sample preparation area and the storage area. In small laboratories, this ideal concept may not be entirely feasible. The proximity of the sample preparation area and the storage facilities may raise the background count slightly, but this may be enough to introduce serious errors at low count rates.

In the ideal situation, the radioisotope complex should consist of two separate rooms: a sample preparation and storage room and a counting room. Sample preparation equipment is rarely allowed in counting rooms in order to avoid any possible contamination of counting equipment, no matter how slight. If the rooms have a connecting doorway, the corridors need not be used for transportation of radioactive material during lab time.

Ideally, both rooms should have seamless floor coverings so that any accidental spills may be mopped up easily. Spillage of long-lived sources in between the cracks of an asphalt-tiled floor makes an extremely difficult decontamination job. In practice, standard tile floors serve well and the use of short-lived isotopes for student experiments is encouraged to minimize contamination problems and to maximize safety. The workbench tops should have a nonporous surface for ease in decontaminating accidental spills. Many workers cover the entire workbench surface with absorbent paper, even when large trays are used. Sufficient electrical outlets in both rooms are necessary for the many devices which will be acquired eventually.

A hood should also be available, if possible, for both storage and handling of certain radioactive materials. High activity materials may thus be stored in the hood behind bricks of either the ordinary building type or the more expensive lead type. A few cabinets with small drawers are also handy for storage of small items. Tackboards for the display of charts are also needed.

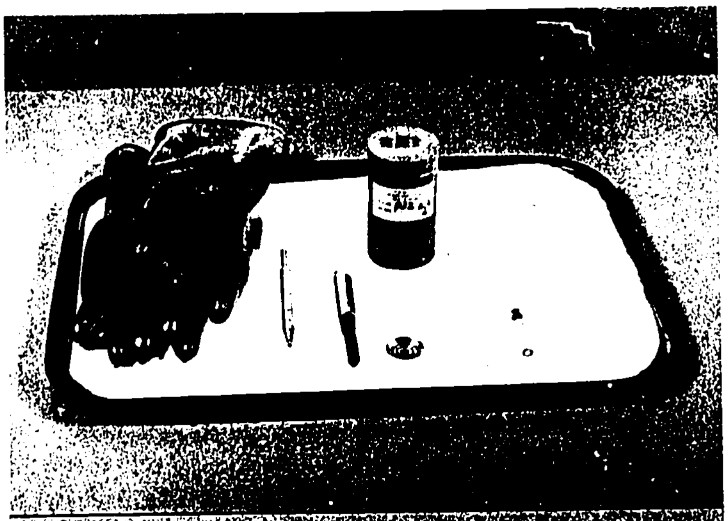
Most college radiochemical laboratories are also air-conditioned to minimize changes in instrument efficiency, and at the same time to increase worker comfort, especially for summer courses. You will note that these are features of any well-designed laboratory and not only of a laboratory specifically designed for use with radioactive materials. Actually, almost any kind of laboratory can be adapted to fit nuclear science needs.

At the high school level, where possibly the only instruments are a scaler and a ratemeter, where radioactive material is used for periods of short duration or only at intermittent times, where space may be at a premium, and where low levels of radioactivity are encountered, certain adjustments must be made. The sample preparation area may be on the same table as the counting instruments if shielded with a row or two of ordinary building bricks to minimize background. The counting area may be a little used corner of the laboratory or the teacher's preparation area. Large closets or janitors' rooms have been appropriated and found quite satisfactory for counting areas. Alcohol lockers and small lockable cabinets have been used for storage of radioactive materials. Existing facilities have been adapted by enterprising instructors in a variety of ways, almost always satisfactorily.

DECONTAMINATION

Even when the most stringent practices and safeguards are in evidence, an accidental spill of radioactive material may occur. If all preparatory work is performed over trays lined with absorbent paper, the spill is localized and easily cleaned up. In the event a table top or floor is contaminated with radioactive material, it still may be decontaminated easily.

The spill should be wiped up with absorbent paper first (be certain to wear gloves while doing so), and then the area should be scrubbed with a strong abrasive cleanser. A good scrubbing with any modern household cleanser will decontaminate almost any nonporous surface. The rags, towelling, etc., used in the scrubbing should be assigned to the proper waste receptacle. Most laboratories keep a step-on can to be used solely for radioactive waste. Scrubbing should be continued until the area shows little or no count above background. Porous surfaces such as wood may be scrubbed as much as possible and then sanded to remove completely any evidence of contamination.



To minimize problems resulting from accidental spills, handle radioactive liquids in a tray lined with absorbent paper.

Contaminated clothing and other fabrics may be easily decontaminated by hot-water machine washing with a strong household detergent. The cleaning action will be much more efficient if some "Calgon" is added to the wash water.

To prevent needless contamination of laboratory sinks, one sink should be designated as a "hot sink." This sink and only this sink should be used for disposal of certain types of radioactive waste.

Glassware which is used with radioactive materials should be segregated from other laboratory glassware. A small dab of a permanent paint may be placed on it, or a diamond tipped etching tool may be used to mark it. A small "R" above the marker spot is sufficient. Beakers and other glassware marked with the approved radiation symbol are now available from commercial suppliers at a slight increase in price.

Decontamination of glassware is not especially difficult; a good soak in a powerful laboratory detergent followed by a scrub with an abrasive cleanser will decontaminate all but the most stubborn radioactive deposits.

One good cleaning procedure is to soak the contaminated article in chromic acid (100 grams of $K_2Cr_2O_7$, potassium dichromate, and 400 ml conc. H_2SO_4, sulfuric acid, to make one liter of solution). This acid cleaner should never be used for decontamination of radioisotopes which evolve gaseous byproducts upon contact with acids, such as carbon 14 and iodine 131 compounds, unless the decontamination takes place in a hood in perfect working order. After the initial decontamination step, the articles should be rinsed many times with running water only in the "hot sink."

When dry, the glassware should be monitored with a G-M counter to see if any radioactivity remains. A count not higher than usual background is evidence of decontamination. If any residual radioactivity remains, the article should be returned to the decontamination procedure for a longer time. If three attempts do not decontaminate the article, it should be discarded with other radioactive materials. It is not economical to use a dollar's worth of chemicals to decontaminate a fifty-cent beaker.

Large laboratories and others with large quantities of items to decontaminate make effective use of ultrasonic decontaminating apparatus. Although expensive to purchase, such a device can prove economical in the long run.

It is worth noting once more that the use of short-lived isotopes, when possible, will reduce contamination problems. As the material decays, the contamination problem disappears.

STORAGE OF RADIOACTIVE MATERIALS

Most radioactive materials, up to and including millicurie quantities, can be stored safely in the original containers. License-free sources are usually supplied in a glass bottle enclosed in a thin metal or cardboard can. This amount of shielding is quite adequate for the quantities involved. Larger quantities of radioactive materials are supplied in glass bottles enclosed in small lead containers. These lead containers provide adequate shielding for millicurie quantities of radioactive materials, even those which emit gamma rays. Ordinary building bricks, staggered around the sources in a double row, provide additional shielding of stored samples. This method of shielding is far less expensive than the use of lead bricks, but about five times the thickness is required to provide the same degree of shielding.

Small wooden, plastic, or sheet metal cabinets make excellent storage facilities for small quantities of radioactive materials. Cabinets about the size of an ordinary laboratory drying oven may be easily constructed in the school shop or purchased from commercial sources. A small lock is suggested to forestall the curious eyes of the young or other unauthorized personnel. The materials must be secured against pilfering.

The smaller sealed sources may be kept in plastic boxes such as those obtainable from supply houses and pharmacists. In many cases, especially with alpha and weak beta sources, this thin plastic box will provide sufficient shielding for safe storage.

Of course, all containers, boxes, lead shields, and cabinets should be marked with the proper yellow-and-magenta warning labels approved by the Atomic Energy Commission.

WASTE DISPOSAL

The "Rules and Regulations" of the Atomic Energy Commission provide several ways for the disposal of radioactive waste. These are:

a. by transfer of the waste to an authorized recipient such as a licensed commercial radioactive waste collection service,
b. by any method desired by the user not otherwise authorized by the regulations, provided special approval has been granted by the AEC,
c. by release into sanitary sewerage systems, and
d. by burial in soil.

The regulations also stipulate that radioactive materials *shall not* be disposed of by incineration except as specifically approved by the Commission.

There is one additional method for the disposal of radioactive waste not mentioned in the regulation, namely, radioactive decay. If the radioactive material is stored safely for a period of one half-life, half of the problem of waste disposal disappears, and in another half-life period, half of the remaining problem disappears. But, of course, this is an example of Zeno's paradox since the radioactivity will never completely disappear. Nevertheless, when one considers that only about 0.1 percent of the original radioactivity remains after 10 half-life periods, a substantial reduction of the waste disposal problem has been achieved.

For laboratories where large quantities of radioactive materials are used under an AEC specific license, it may be advantageous to use the services of a commercial concern specializing in the disposal of radioactive waste. Fees for this service are nominal.

For the average small user of radioisotopes it is suggested that radioactive liquid waste and radioactive solid waste be collected in separate containers. Glass or plastic narrow-mouthed bottles are convenient for the collection of radioactive liquids. A funnel is placed in the neck of the bottle to minimize spillage. Wide-mouth containers—beakers, bottles, or step-on metal cans with plastic bag liners—are used for the collection of solid waste. Each container should be labeled for identification. It is advantageous to keep short-lived waste separated from long-lived waste so one can take full advantage of radioactive decay as a means of disposal.

Liquid wastes can be discarded through the sanitary sewerage system. A separate sink should be reserved for this purpose and the type and amount of each isotope must be known so the *diluted* quantities indicated in Table 3 will not be exceeded. Table 3 was compiled from data given in the "Rules and Regulations" of the Atomic Energy Commission. Materials discarded through the sanitary sewerage system must be either soluble or dispersible.

When averaged over a period of a day, the concentration of a specific soluble isotope released to the sewer must not exceed the value given in column A (or in column B if it is insoluble but dispersible) OR the total quantity of a specific isotope discharged to the sewer in a single day must not exceed the quantity listed in column C, whichever is the larger, provided that the quantity released in any one month, if diluted by the average monthly quantity of water used by the licensee, will not result in an average concentration exceeding the limits specified in columns A and B. Under no circumstances must the gross quantity of material discharged to the sewer exceed one curie per year. These regulations are sufficiently liberal that the average user of small amounts of radioisotopes should have no difficulty disposing of liquid waste.

The disposal of solid waste is a little more troublesome, but good laboratory techniques can minimize this problem. Care should be used not to dilute radioactive waste with nonradioactive waste in order to keep the bulk to a minimum. For example, bulk can be reduced by localizing contamination as by placing contaminated pipettes on small facial tissues, thus keeping the underlying heavy protective paper on the desk top clean.

TABLE 3—DISPOSAL BY SANITARY SEWERAGE SYSTEM

	A	B	C
Isotope	*Concentration of Soluble Waste µCi/Liter*	*Concentration of Insoluble Waste µCi/Liter*	*Daily Quantity µCi*
Antimony 124	0.8	0.8	100
Arsenic 76	0.6	0.6	100
Barium 140	0.8	0.7	100
Calcium 45	0.3	5.0	100
Carbon 14	20		1,000
Cesium 137	0.4	1.0	100
Chlorine 36	2.0	2.0	100
Chromium 51	50	50	10,000
Cobalt 60	1.0	1.0	10
Gold 198	2.0	1.0	1,000
Hydrogen 3	100	100	10,000
Iodine 131	0.06	2.0	10
Iron 55	20	70	1,000
Iron 59	2.0	2.0	100
Nickel 63	0.8	20	100
Phosphorus 32	0.5	0.7	100
Polonium 210	0.02	0.8	1
Radium 226	0.0004	0.9	0.1
Silver 111	1.0	1.0	1,000
Sodium 22	1.0	0.9	
Sodium 24	6.0	0.8	100
Strontium 90	0.02	1.0	1
Sulfur 35	2.0	8.0	1,000
Technicium 99m	20	8.0	1,000
Thallium 204	3.0	2.0	100
Tin 113	2.0	2.0	100

It is especially helpful to keep short-lived solid waste separated from long-lived solid waste. To dispose of short-lived material one can store it for decay, but in light of Zeno's paradox one is always left with the decision of when a radioactive material becomes nonradioactive. In practice, it is safe to say that license-free quantities of isotopes will have decayed to an undetectable level in about 10 half-lives.

Burial in soil of up to 100 times the amount listed in column C of Table 3 is permitted. Burial must be at a minimum depth of four feet. Successive burials of similar amounts are permitted but must be separated from each other by at least six feet and not more than 12 burials can be made in any one year.

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