4 Radiation Safety Principles

Radiation doses to workers can come from two types of exposures, external and internal. External exposure results from radiation sources outside of the body emitting radiation of sufficient energy to penetrate the body and potentially damage cells and tissues deep in the body. External exposure is type and energy dependent. As a general rule, x-rays, γ-rays and neutrons are external hazards as are β-particles emitted with energies exceeding 300 keV ($E_{\text{max}} > 300$ keV). Beta particles with $E_{\text{max}} < 300$ keV (such as $^3$H, $^14$C, $^33$P, $^35$S, $^45$Ca, $^{59}$Ni) do not travel far in air and most of the beta particles (i.e., > 90%) do not have enough energy to penetrate deeper than 0.1 mm of skin (see Table 1-3).

Internal exposure comes from radioactivity taken into the body (e.g., inhalation, ingestion, or absorption through the skin) which irradiates surrounding cells and tissues. Both types of exposure carry potential risk. Thus, when using radiation or radioactive materials, workers must understand and implement basic radiation safety principles to protect themselves and others from the radiation energy emitted by the radioactive materials and from radioactive contamination in the work place. The principles of time, distance and shielding apply only to external hazards.

4.1 Time

The linear no-threshold dose-response model assumes no cellular repair and that radiation damage is cumulative. Therefore, the length of time that is spent handling a source of radiation determines the radiation exposure received and the consequent injury risk. Most work situations require workers to handle radioactive materials for short periods. For new procedures, a worker can reduce this "timely" radiation exposure by first practicing the new procedures with simulated radiation sources. These dry runs enable the worker to become proficient. Once proficient, the worker may be able to work more rapidly with real sources and thus receive a lower exposure than if they had gained that proficiency using real radiation.

4.2 Distance

Radiation is affected by distance like light. Up close a light bulb appears bright, but as one moves away the light grows dim. Similarly, the exposure rate from a radiation source decreases with distance. Gamma ray exposure from a point source (i.e., distance > 7-times the dimension of the source) of radiation follows the Inverse Square Law. This specifies that if you double the distance from the radiation source, the radiation intensity will decrease by a factor of 4. For example, if the unshielded radiation intensity at 50 cm from a 370 MBq (10 mCi) vial of $^{22}$Na is 50 mR/hr, then at 100 cm from the source, the radiation intensity will decrease to 12.5 mR/hr, and at 200 cm (i.e., twice 100 cm, 4 times 50 cm) the intensity will only be 3.1 mR/hr.

Beta particles do not follow the inverse square law (see Table 4-4). Increasing the distance from a source of radiation is often the most effective way of decreasing exposure. Do not stand near unshielded radiation sources unless actually working with the radiation. When it is not necessary for you to handle radioactive materials, stand at least 6 feet from the source. The exposure at 6 feet is only 2.8% the exposure at 1 foot. If you must work with high activity (i.e., > 37 MBq [1 mCi]) sources, work at arm's length, use tongs, or long-handled tools to increase the distance to your hands and your whole body.

4.3 Shielding

Penetrating radiation deposits energy and produces ion pairs as it passes through matter. Anything placed between the source of radiation and the worker will absorb some of the radiation energy and reduce subsequent exposure. A shield is a material of some thickness which will stop or effectively reduce radiation exposure to nonhazardous levels. Because different radionuclides emit different types and energies of radiation (see Table 1-4) with different penetrating powers (see Figures 1-17 & 1-18), different types of radiation require different types and thicknesses of shielding material to absorb the radiation. Table 4-1 lists various routinely used radioisotopes, the type and...
thickness of shielding material to reduce the x-/γ-ray exposure by a factor of 10 (e.g., from 100 mR/hr to 10 mR/hr) or to stop essentially all of the beta radiation.

### 4.3.a Alpha Particles

Because of their large size and charge, alpha particles are stopped by very thin absorbers. A sheet of paper or thin aluminum foil will absorb all the alpha particles from any source. Energetic alpha particles travel only about 5 cm in air and 0.037 mm in tissue (see Figure 1-17). The dead layer of the skin will stop all alpha particles with no harmful effect. Thus, alpha particle radiation is not considered an external hazard.

### 4.3.b Beta Particles

Just like alpha particles, beta particles interact electromechanically with orbital electrons (see 1.2.e). Because a beta particle has a much smaller mass than an alpha particle, for the same kinetic energy it will have a greater velocity (i.e., \(E = \frac{1}{2}mv^2\)). The high velocity means the time a beta particle spends near an atom or molecule is shorter than for an alpha particle, the beta particle is less densely ionizing (i.e., lower LET) and will penetrate farther into an absorber than an alpha particle. For a beta particle to be capable of penetrating the dead layer of the skin it must have an effective energy (i.e., \(E_{\text{eff}} = \frac{1}{2}E_{\max}\)) greater than 70 keV (0.07 MeV). Consequently, most low energy beta radiation (e.g., \(^3\text{H}, ^{14}\text{C}, ^{33}\text{P}, ^{35}\text{S}, ^{45}\text{Ca}\)) is not considered to be an external hazard and is only a slight skin exposure hazard.

Shielding of high-energy beta particles is done by using light materials (e.g., plastic, Lucite, aluminum, etc.). As seen in Table 4-1, a few millimeters of plastic will stop even the high energy beta particles from \(^{32}\text{P}\). Dense materials (e.g., lead) are not suitable for stopping high energy (> 500 keV) beta particles because, as the beta particles slow down in dense shields they produce a type of x-ray called bremsstrahlung, or braking radiation (see Figure 1-12). Thus, using a lead shield for beta-particles absorbs the particulate beta and produces penetrating x-rays. Shielding high-energy beta particles with light materials do not produce as much bremsstrahlung (e.g., a factor of 10 less) as in dense materials. Thus plastic or Lucite is the preferred shielding material for high-energy beta emitters. Additionally, shielding is not needed for low energy (< 300 keV) beta particles, but, if you are using more than 7.4 MBq (0.2 mCi) of a beta-emitting radioisotope, some bremsstrahlung is likely, even from stock vials of \(^{33}\text{P}\) and \(^{35}\text{S}\).

#### Beta Skin Dose

Most (80 - 85%) of the research work on campus uses beta emitting radionuclides. Beta particles are not penetrating (Figure 1-17). For example, the beta particle emitted from \(^{35}\text{S}\) will only penetrate skin to a depth of 0.3 mm and the beta particle from \(^{32}\text{P}\) only penetrates a maximum of 8 mm in skin. Thus, the major tissue subject to radiation damage from external beta particles is the skin. Because the skin is less sensitive to radiation injury, the limit for skin exposure is 0.5 Sv (50 rem) per year, 10 times the limit for whole body exposure (Table 3-2).

However, on the negative side, because all of the energy of the beta particle is absorbed within approximately \(\frac{1}{2}\) centimeter of tissue, the dose from even a small drop of concentrated beta-emitting radioactivity may be quite high. Table 4-2 estimates skin exposure rate (mrem/hr) per activity (\(\mu\text{Ci}\) or kBq) from commonly used beta emitting radionuclides (\(^3\text{H}\) is not an external hazard, the energy is too low to even penetrate the dead layer of the skin). Using the table, if you had a 37 kBq (1 \(\mu\text{Ci}\)) drop of \(^{32}\text{P}\) on your skin for 1 hour, the immediate square centimeter of skin

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Symbol</th>
<th>Exposure (mR/hr)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium-22</td>
<td>(^{22}\text{Na})</td>
<td>13.3</td>
<td>27.9</td>
</tr>
<tr>
<td>Phosphorus-32</td>
<td>(^{32}\text{P})</td>
<td>353*</td>
<td>--</td>
</tr>
<tr>
<td>Phosphorus-33***</td>
<td>(^{33}\text{P})</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sulfur-35***</td>
<td>(^{35}\text{S})</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Calcium-45***</td>
<td>(^{45}\text{Ca})</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chromium-51</td>
<td>(^{51}\text{Cr})</td>
<td>0.18</td>
<td>5.6</td>
</tr>
<tr>
<td>Zinc-65</td>
<td>(^{65}\text{Zn})</td>
<td>3.0</td>
<td>33.2</td>
</tr>
<tr>
<td>Rubidium-86</td>
<td>(^{86}\text{Rb})</td>
<td>0.56</td>
<td>32.5</td>
</tr>
<tr>
<td>Technetium-99m</td>
<td>(^{99m}\text{Tc})</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Iodine-125</td>
<td>(^{125}\text{I})</td>
<td>0.78</td>
<td>0.056</td>
</tr>
<tr>
<td>Iodine-131</td>
<td>(^{131}\text{I})</td>
<td>2.4</td>
<td>9.7</td>
</tr>
<tr>
<td>Cesium-137</td>
<td>(^{137}\text{Cs})</td>
<td>3.7</td>
<td>21.0</td>
</tr>
</tbody>
</table>

*Unshielded exposure rate (mR/hr) 30 cm (12 inch) from 37 MBq (1.0 mCi) source

**Lead to reduce γ exposure rate by factor of 10 (two TVL reduce exposure by a factor of 100) or Lucite to stop all β

*Radiation from pure beta emitting radionuclides is technically not measured in mR/hr (see 4.3.b.1) and should not be shielded with lead; shield beta-particles with Lucite/plastic

*If gamma is attenuated by a factor of 10, dose rate from Bremsstrahlung x-rays (cf. 1.2.a.3 & 4.3.b) should also be low

***There is no need to shield low-energy β-particles \(^{14}\text{C}, ^{33}\text{P}, ^{35}\text{S}, ^{45}\text{Ca}\)
would receive an exposure of approximately 6 rem (0.06 Sv). Furthermore, the time needed to exceed the annual skin dose limit for just 37 kBq (1 μCi) of $^{32}$P contamination for a 1 cm$^2$ skin area is only about 8.4 hours.

Because high beta skin doses are possible, Radiation Safety requires every lab which uses beta radionuclides to have a calibrated thin-window GM. Without using a GM, it is impossible to know if there is skin contamination which may lead to either a possible overexposure, a dosimetry problem, a contamination problem, or all three.

All thin-window radiation survey meters used at the UW are calibrated using 3 different energies of beta particles, $^{14}$C, $^{99}$Tc, and $^{90}$Sr (cf. 7.5.b). The efficiency of the meter for each of the energies is listed on the calibration sticker that is affixed to the meter. This calibration information can be used in conjunction with the meter’s count rate to estimate contamination activity and to make a cursory estimate of the resultant skin dose.

An efficiency of 10% means the detector is sensing only 1-in-10 decays, so the radioactivity is actually 10-times greater than the count rate (i.e., dpm = cpm/eff => dpm = 10 x cpm). Table 4-3 provides a conversion relationship for the meter used in this example. To accurately estimate the response for any meter in a lab, simply make a similar table for each meter. When calculating the dose from a small drop, assume that approximately 1 square centimeter of skin is contaminated. All of this information can then be used to calculate maximum skin doses from contamination.

For example, after working with $^{32}$P for about ½ hour a researcher detects a small spot of contamination on his/her left wrist that measures about 100,000 cpm. Calculate the skin dose (in mrem) to the researcher’s wrist. Assume the $^{32}$P contamination happened at the beginning of the procedure and the skin was exposed for ½ hour. From Table 4-3, the lab’s GM efficiency for $^{32}$P is about 35% (i.e., 777,000 cpm per μCi) and the $^{32}$P skin dose is 6.0 rem/hr per μCi. The calculation shows that the researcher’s skin dose is approximately 0.386 rem.

\[
dose = 100,000 \text{ cpm} \times 0.5 \text{ hr} \times \frac{1 \text{ μCi}}{777,000 \text{ cpm}} \times \frac{6.0 \text{ rem/hr}}{1 \text{ μCi}} = 0.386 \text{ rem}
\]

Because beta particles are not highly penetrating, they do not quite follow the inverse square law. Table 4-4 lists the absorbed dose rate (rad/hr) from a 37 MBq (1 mCi) point source. Notice the sharp drop in dose rate for low-energy beta-emitters. This is because most of beta particles are emitted in a spectrum approximately ½ of the maximum energy and the low-energy betas are rapidly attenuated in air. But, the measurable dose rate for $^{32}$P / $^{86}$Rb extends to great distances. For these very high energy beta emitters, there is some inverse square effect.

### Beta Skin Protective Measures

Because beta particles are not penetrating and deposit all of the beta energy within a few millimeters of flesh, it is important that you wear protective clothing (disposable gloves, lab coat), monitor the gloves frequently during your procedure and change them either when they are contaminated or periodically. Sometimes a glove may get a pinhole. For that reason, and depending upon the procedure being performed, it may be prudent to wear several (e.g., two or more) pairs of gloves, and dispose of the outer pair when contamination is detected.
The range of a beta particle depends upon the beta particle energy and the type of material it is passing through. Low energy beta particles do not penetrate. Thus, for $^{14}\text{C}$ and $^{35}\text{S}$, a lab coat and single pair of disposable gloves will stop essentially all beta particles. For slightly more energetic (i.e., $E_{\text{max}} \sim 250$ keV) beta particles such as $^{33}\text{P}$ and $^{45}\text{Ca}$, a double pair of disposable gloves will stop all beta particles. Because $^{32}\text{P}$ is so energetic (1.71 MeV), the best protective measures to use are shielding ($\frac{1}{3}$-inch Plexiglas) and distance (2 - 6 feet).

**Beta Detection Considerations**

It is not uncommon to see a GM probes covered with Parafilm M or plastic laboratory film in an effort to prevent the detector from becoming contaminated. Most workers assume that such a thin membrane will have little effect on the detector efficiency. But, they are wrong. There is a significant reduction in detection efficiency for low energy betas (e.g., $^{14}\text{C}$, $^{33}\text{P}$, $^{35}\text{S}$, and $^{45}\text{Ca}$) from laboratory film. The maximum range for the low energy betas is about 5 - 7 cm in air and much less in any solid, even a thin solid like Parafilm M or laboratory film. Table 4-5 summarizes the effect on efficiency for major beta energies for no film, cling film, and Parafilm M.

The detection of $^{32}\text{P}$ is never an issue and the impact of covering the end of the GM tube with film is negligible. However, there is a lot of attenuation of low energy beta particles from $^{14}\text{C}$, $^{33}\text{P}$, $^{35}\text{S}$, and $^{45}\text{Ca}$. Parafilm M attenuated more than 95% of the betas from $^{14}\text{C}$ and $^{35}\text{S}$. The laboratory cling wrap stopped more than 35% at these energies. As the $E_{\text{max}}$ increases, the attenuation of beta particles becomes less; being only about 75% and 16%, respectively for $^{33}\text{P}$ and $^{45}\text{Ca}$.

Remember, placing any material between a detector and a beta-emitting radionuclide will affect the detector efficiency. The Safety Department recommends that detectors not be covered. However, if you must cover the detector while certain procedures are under way, laboratory film is preferable over Parafilm M and always remove the film before performing your final surveys.

### 4.3.c Gamma Rays

Unlike $\alpha$ and $\beta$ particles, gamma rays do not lose energy rapidly when passing through matter. Figure 1-17 shows that the average distance between interactions for the $^{125}\text{I}$ $\gamma$-ray ($E = 35$ keV) is about 33 mm compared with 3100 Å ($1 \text{ Å} = 0.0000001 \text{ mm} \Rightarrow 0.00031 \text{ mm}$) for $\beta$- and 15 Å ($0.0000015 \text{ mm}$) for $\alpha$-particles. Thus, gamma ray photons are much more penetrating than $\alpha$- or $\beta$-particles. Until the photon interacts, no energy is given up to the matter. When gamma-rays do interact, they ionize (i.e., eject orbital electrons). It has been observed that the number of gamma-ray interactions is proportional to the number of orbital electrons in the matter. Dense material such as lead and iron usually have more orbital electrons per cubic centimeter than light material like aluminum. For that reason, shielding of x/-$\gamma$-rays is best accomplished by using dense materials (e.g., lead, tungsten, uranium, etc.) or a great thickness of less dense, but less expensive (e.g., steel, concrete), material. Lead is preferred because of its great density and low cost. Gamma- and x-ray beam intensities with maximum energies less than 2.0 MeV will be reduced by at least a factor of 10 (Table 4-1) by using 2-inches of lead. Protective "lead" aprons are not effective in shielding radionuclides with $\gamma$-ray energies exceeding 0.05 MeV or 50 keV. Do not use lead aprons with $^{51}\text{Cr}$, $^{99m}\text{Tc}$, etc., it may give a false sense of security.

Because gamma rays travel greater distances between interactions than $\alpha$/-$\beta$-particles travel, they do not deposit as much energy per centimeter of tissue as do $\alpha$/-$\beta$-particles (i.e., $\gamma$-rays are low LET). That means the absorbed dose (i.e., J/kg or erg/gm) for gamma rays is much less than for beta particles. However, the range and consequent distance over which this absorbed dose occurs is much greater. The major $\gamma$-ray emitting nuclides used on campus are $^{51}\text{Cr}$, $^{86}\text{Rb}$, $^{99m}\text{Tc}$, and $^{125}\text{I}$. Table 4-6 lists the gamma doses for each of these nuclides at a distance of 1 cm. Of particular interest is the very low dose per kBq ($\mu$Ci) of skin contamination. While this dose is low, unlike

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$E_{\text{max}}$ (MeV)</th>
<th>Percent Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unshielded</td>
<td>Cling Film</td>
<td>Parafilm M</td>
</tr>
<tr>
<td>$^{14}\text{C}/^{35}\text{S}$</td>
<td>0.160</td>
<td>4.05</td>
</tr>
<tr>
<td>$^{33}\text{P}/^{45}\text{Ca}$</td>
<td>0.250</td>
<td>8.90</td>
</tr>
<tr>
<td>$^{32}\text{P}$</td>
<td>1.710</td>
<td>22.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Energy (MeV)</th>
<th>Dose (mrem/hr per $\mu$Ci)</th>
<th>Dose (mrem/hr per kBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{51}\text{Cr}$</td>
<td>0.320</td>
<td>0.16</td>
<td>0.004</td>
</tr>
<tr>
<td>$^{86}\text{Rb}$</td>
<td>1.078</td>
<td>0.5</td>
<td>0.014</td>
</tr>
<tr>
<td>$^{99m}\text{Tc}$</td>
<td>0.1427</td>
<td>1.1</td>
<td>0.030</td>
</tr>
<tr>
<td>$^{125}\text{I}$</td>
<td>0.0355</td>
<td>1.56</td>
<td>0.042</td>
</tr>
</tbody>
</table>
beta-particle absorbed dose, gamma-ray dose is deposited over a greater depth, decreasing primarily according to
the inverse square law (cf. 4.2).

The $6CEn$ formula is a rule-of-thumb which can be used to estimate the gamma-ray dose rate. It will provide a
dose estimate with $\pm$ 20% of the actual dose for photon energies between 70 keV (0.07 MeV) and 2 MeV. Within
this energy range, the exposure rate in mR/hr at 1 foot from a 1 mCi x-/$\gamma$-ray point source is approximately $6CEn$,
where $C$ is the activity in millicuries, $E$ is the photon energy in MeV, and $n$ is the relative photon abundance (e.g.,
for $^{51}$Cr and $^{86}$Rb, only 1 in 10 decays [10%] results in a gamma emission). For example, at 1 foot the exposure rate
from a 5 mCi vial of $^{51}$Cr ($E = 0.32$) is:

$$Dose = 6CEn = 6 \cdot (5 \text{ mCi}) \cdot (0.32 \text{ MeV}) \cdot (0.10) = 0.96 \text{ mR/hr}$$

Doses at other distances would follow the inverse square law, so at 2 feet it would be 0.24 mR/hr and at 1 meter
(i.e., 3.3 feet) would be approximately 0.097 mR/hr.

4.3.d Positrons and Mixed Beta / Gamma Emitters
The shielding of radionuclides that emit both high energy beta and gamma radiation (e.g., $^{18}$F, $^{22}$Na, $^{86}$Rb, $^{131}$I, etc.)
is more complicated. Ideally, a graded shield is used. Nearest the source, light material (e.g., aluminum, Lucite) is
used to stop the beta particles. Next to the light material, dense material (e.g., steel, lead) is used to stop the gamma
rays and any bremsstrahlung x-rays produced in the light material. However, for most practical applications involv-
ing beta-gamma emitters, using enough lead to reduce the gamma exposure rate by a factor of 10 is usually suffi-
cient to stop the beta and any bremsstrahlung x-rays produced.

4.4 Practical Application
While time may be a factor over which the radiation worker has very little control, the factors of
distance and shielding can be used together to keep exposures ALARA. Figure 4-3 shows the use of
both lead shielding and distance to reduce the exposure from a 37 MBq (1 mCi) stock vial of $^{125}$I.
As noted in Table 4-1, it does not require a great
thickness of lead to reduce the exposure from the
35 keV x-/$\gamma$-ray to essentially zero. If a worker stands behind the 1/8” lead shield, then only the hands and arms are
exposed depending upon position from the stock vial.

4.5 Housekeeping
Many research procedures at the University use unsealed sources of radiation. The deposition of unsealed radioac-
tive material in the body can result in prolonged internal radiation exposure (cf. Table 2-5). Radioactive materials
can enter the body through inhalation, ingestion, wound penetration, or skin absorption. Once inside the body, the
potential for cellular damage by particulate (especially $\alpha$ and low-energy $\beta$ particles) radiation is often greater than
if the same radiation source were outside the body. Thus, it is essential that radiation workers utilize the basic
principles of time, distance, and shielding in combination with good housekeeping practices to keep radionuclides
from getting inside the body. When working with radioactive materials, consider the following precautions to help
insure that radiation exposure (and consequent risk) will be As Low As Reasonably Achievable.

- Always wear protective clothing (e.g., disposable gloves, lab coat, safety glasses) when handling radioactive
  materials; these protect skin and clothing from contamination and shield the skin from beta particle absorbed
dose. Monitor frequently. Remove gloves and wash hands when finished. Leave lab coat in the lab when you
  leave.
- Do work in a fume hood if gas, vapor, dust or aerosols can occur during the procedure.
- Do not eat, drink, or perform other hand-mouth procedures (e.g., licking stamps or labels, applying makeup,
  etc.) in any room or lab which has been posted Caution - Radioactive Materials. Do not mouth pipette, not
even water. Bad practices, once started, may become habitual with the consequent risk of ingestion of radioac-
tive materials or other toxic substance.
- Lock and secure stock vials when not in use.
Do not store food or drink containers in the same location as radioactive materials. This particularly applies to refrigerators containing (or labeled as containing) radioactive materials; these refrigerators are off limits for lunch bags, milk cartons, and other food or drink containers.

Do not bring personal belongings into the radioactive work areas of the lab. Avoid wearing rings, watches, and similar items during work. Wearing shorts, sandals, or slippers is also not recommended.

If issued a radiation dosimeter (see Chapter 7), wear it/them when working with radiation sources.

Do not work with radioactive materials if you have an open cut or wound; contamination may enter the body through a cut.

Assume containers labeled Caution - Radioactive Materials are also contaminated and wear disposable gloves when handling all such containers.

Employ the three basic safety principles of time, distance and shielding whenever you work with external hazards and employ good housekeeping techniques when using any radioactive material.

When doing a new procedure, perform a "dry run" without radioactive materials to learn the procedure.

Do liquid radiation work on a non-porous tray which is capable of containing the entire volume of a liquid radioactive material in case it is spilled. Cover the work area with plastic-backed absorbent material.

Immediately after use or work with radioactive materials, wash hands then monitor them thoroughly. Monitor hands and clothing for radioactive contamination during and after work; especially before leaving the lab. If you are contaminated or suspect you are contaminated, wash the contaminated area and re-monitor (cf. Chapter 6 and Chapter 7) as necessary; notify Safety of problems.

Monitor the rooms where radioactivity is used or stored, and pay special attention to all areas which may come in contact with potentially contaminated hands, e.g., phone, door knob, refrigerator handle.

Workers should be thoroughly familiar with the properties of the radionuclides they are using. If you are uncertain about the safety of a procedure or have any questions about radioactivity call Radiation Safety.

4.5 Review Questions - Fill in or select the correct response

1. The 4 techniques to reduce radiation exposure are: ________, ________, ________, and ________.
2. Shield gamma emitters with ____________ materials.
3. Lucite is the best material to shield beta emitters. true / false
4. The skin dose from a 37 kBq (1 μCi) drop of 32P is ________ mrem/hr.
5. Do / Do not eat, drink, smoke, mouth pipette in a radiation work area.
6. Do / Do not store food or drink containers in refrigerators which contain radioactive materials.
7. After radioactive materials work, you should monitor your work area, then ________ and monitor your hands before leaving the lab.
8. Always do radiation work on a ________ which is capable of containing the entire volume of a liquid radioactive material spill.
9. If you have an open cut, do / do not work with radioactive materials.
10. If you are contaminated with radioactivity, ________ the contaminated area then contact Safety.
11. Procedures that may produce airborne radioactive materials must be done in a ____________.
12. Disposable gloves will stop all beta particles from 35S. true / false
13. Per unit of activity (e.g., per mCi or kBq) the skin dose from gamma emitters is (greater than) (less than) the skin dose from beta emitters.

4.6 Reference