General Goals:
To provide a sufficient information about radiation safety to allow students to safely work in PAS 284.

Reading:
*Introduction to Radiation Safety*, by the University of Arizona Radiation Control Office (attached to this document)

Units used when discussing radiation
When discussing radiation safety, it is necessary to know how radiation is measured. That is basically a discussion of units.

The curie (abbreviated Ci) is a measure of the activity of the sample that is the number of nuclear disintegrations in a given time. Specifically the curie is $3.7 \times 10^{10}$ disintegrations per second, which is the activity of a gram of radium. In the SI system of units, the curie has been replaced by the becquerel (Bq) with 1 curie = $37 \times 10^9$ Bq, so a Bq is one disintegration per second.

The activity of a source (in Ci or Bq) is one way to describe the amount of radiation present. An alternative method is to give the flux of radiation. That is the number of quanta (alpha, beta, gamma, protons, chickens . . . or whatever) incident on a unit area per unit of time (for example the number of betas incident on 1 cm$^2$/s).

There is another type of radiation unit that is related to the interaction of radiation with living tissue. As radiation passes through matter, it interacts and in general deposits energy in the matter. A rad of radiation will deposit 100 ergs of energy for each gram of tissue it passes through. Starting from the activity of a source or the flux of the radiation and converting to rads is not a simple process. This involves details of the interaction between the specific type of tissue and the specific type and energy of the radiation. Recently SI replaced the rad with the gray (Gy). A gray of radiation will deposit 10,000 ergs of energy for each gram (or 1 J/kg) of tissue it passes through (100 rad = 1 Gy).

Even when losing the same amount of energy in a given bit of living tissue, different kinds of radiation cause different degrees of damage. This is because for some type of radiation a given particle may interact relatively infrequently, but deposits a relatively large amount of energy during each interaction, while a particle of different type of radiation, may interact frequently, but lose only a small amount of energy in each interaction. The energy deposited per gram of tissue may be the same but the damage is different. Thus a further set of units is needed.

The rem (roentgen equivalent unit (a roentgen is basically 1 rad of gamma’s)) is the standard old unit for radiation damage and the sievert (Sv) is the new SI unit. 100 rem = 1 Sv. The amount of radiation present in Gy, is multiplied by an RBE (relative biological effectiveness) factor to yield the amount of radiation damage in sieverts. The RBE for x rays, gammas and betas is 1, protons it is 10 and for alpha it is 20. Thus the same number of rads or grays of alphas in much more damaging the equivalent amount of gammas.

Note the rem or the sievert do not indicate how quickly the damage was done. So often the radiation field is reported in rem/hr or mrem/year or Sv/year. Acceptable limits of radiation exposure have decreased over the years as more information on the long term effects of radiation have become available.

Typical Exposures
Typical exposures per year to a member of the public may include:

- 35-60 mrem (~0.0005 mrem/hr) from cosmic rays (strong altitude dependance)
- 35-70 mrem (~0.0005 mrem/hr) from natural radioactive sources
- 30-350 mrem (~0.0005 - 0.005 mrem/hr) from all natural radioactivity that includes sources within the body
  - 25 mrem from $K^{40}$
  - 1 mrem from $C^{14}$
  - remainder from Ra$^{226}$
- 100 mrem from medical x-rays.
- 4 to 8 mrem (0.0005 to 0.001 mrem/hr) estimate of exposure in the Physics and Atmosperic Science Building at the University of Arizona.
- 0.001 mrem/hr typical poker chip source at one meter.
Legal Limits of Exposure
These limits are set by various government agencies and are subject to change.
For the general public (Or Students) the acceptable whole body exposure is:
   100 mrem/yr = 1 mSv/yr,
For radiation workers the limit is
   5000 mrem / yr.
If the radiation exposure is limited to the skin or extremities, the limit is even higher.

Official Information:
Arizona Regulations dealing with radiation safety and radiation workers’ rights can be found on the table near the radioactive source cabinet.
On the door of the radioactive source cabinet are:
   Notice to Employees
   Radiation Emergency Procedure
   Basic Laboratory Procedure for Radioactive Materials
   Rules for Package Radioactive Waste
   Radioactive Materials Approval List (Basically an inventory of sources requiring approval)

Sources and Location:
The radioactive source cabinet is in the North East (After entering the room this is the far left) corner of PAS 284. This cabinet should be locked unless PAS 284 is occupied.
In PAS 284 there are three sources that require approval.
• 15 mCi Cs-137 is a beta and gamma source used for Compton scattering experiments. This sealed source stored in a lead pig inside the radioactive source cabinet. This source is quite hot, and SHOULD BE HANDLED ONLY BE THE LAB MANAGER or other train individuals and then only at arms length and for as short of time as possible. The lead pig used for storage and the lead shielding used in the Compton experiment reduce the emitted gamma radiation to a level similar to a “poker chip” source.
• 0.001 μCi Am-241 is an alpha source used for studying the range and energy loss of alphas in gases. This source is a foil implanted with Americium and is mounted in a 9 by 5 inch vacuum chamber. It is stored in the radioactive source cabinet. Am-241 is an alpha emitter and all alpha emitters are potentially dangerous because alphas can cause serious cell damage. This damage usually only occurs if the alpha emitter is ingested because alphas have a very limited range. Virtually all alphas emitted by this source all absorbed by the vacuum chamber housing. Unless the housing is opened this source is quite safe. NO NOT OPEN THE VACUUM HOUSING
• 16 gram of Pu-239 mixed with beryllium is a neutron source used in neutron activation experiments. This source is in a large brown drum (a neutron howitzer) stored near the radioactive source cabinet. This drum is filled with paraffin that is an excellent shielding material for neutrons.
The cabinet also contains a number of low activity test sources the size of a poker chip, lantern mantles containing thorium and other low level radioactive materials.

Waste
In these experiments no waste should be generated and neutron activated material are stored in the neutron howitzer after the experiment.

One of our typical “poker chip” sources will produce a radiation field a one meter of about 0.001 mrem/hr. A student working with one of the “poker chip” sealed source would reach their annual full body radiation exposure in about 100 hours. This assumes a distance of one meter and no shielding. Note that there are about 75 hours of advanced lab per semester. Double the distance to two meters and the time increases to 400 hour.
Accidents /emergencies
If you believe, a source (including an exempt “poker source”) is damaged contact the lab manager or your TA immediately.
If the radioactive sources are out of the cabinet and there is a fire in the building, please inform the police, or fire departments or the building monitor.

Working procedures:
An official protocol is describing the use of each of the radioactive sources requiring approval. This is a legal document outlining the operational procedures. If you are performing an experiment using one of these sources, you should get a copy of the associated protocol and follow the protocol.

The basic rule of thumb when working with radioactive material is to take all reasonable steps to reduce exposure. The rule is often referred to as ALARA, As Low As Reasonably Achievable. The three basic methods of reducing exposure are:
- minimizing exposure time,
- maximizing distance (Intensity $\propto 1/r^2$), and
- using shielding
  Lead for most forms of radiation
  Paraffin for neutrons
Applying this rule requires that one stop and think before using a radioactive source. Think through what you are about to do.

Lab Rules:
11. No eating or drink in PAS 284! No open food or beverage brought into PAS 284 must be destroyed.
12. The lab PAS 284 must either be occupied or locked at all times.
13. Do not remove any radioactive source including an exempt “poker source” from PAS 284
14. Only Lab manager or specially trained TA or Instructor may move the 15 mCurie Cs -137 source, open the neutron howitzers, or open the Range of Alpha chamber. Please move at least 2 meters from the area when these processes are occurring.
15. Store radioactive sources in the cabinet when not in use.
16. At the end of lab check the inventory to verify all sources are stored.
17. Do not eat a source
18. Do not put a source in your pocket
19. Do not hold a source any longer than necessary

Additional Concerns:
If you are concerned about some aspect of the radiation safety in PAS 284 please discuss it with the Lab Manager or Someone at the Radiation Control Office 626-6850 or rcohelp@u.arizona.edu or http://www.radcon.arizona.edu/.

Pregnancy:
Anyone who is pregnant, thinks they may be pregnant, is engaged in activities to become pregnant should take special steps to limit exposure, and should (but are not required to) discuss the situation with the Lab Manager or someone at the Radiation Control Office 626-6850 or rcohelp@u.arizona.edu or http://www.radcon.arizona.edu/.

Additional Training:
Additional radiation safety training is available through the Radiation Control Office 626-6850 or rcohelp@u.arizona.edu or http://www.radcon.arizona.edu/.