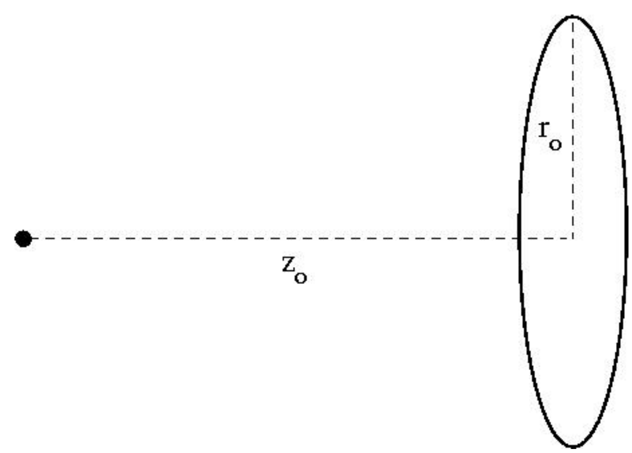
1. **(15 min)** High energy accelerators which are used to produce protons or heavy ions with energies over 100 MeV produce neutrons when charged particles interact with shielding.
   a. **(7.5 min)** Assuming that a radiation field includes both neutrons and high energy charged particles, can pulse shape discrimination be used to identify the neutron events in a high pressure proportional counter?
   b. (**7.5 min)** Will pulse shape discrimination work in a liquid scintillator?

   In each case justify your answer by describing how pulse shape discrimination is used to separate neutron and photon events.

2. **(15 min)** Without explicitly calculating anything or assuming a particular value for an atomic weight, indicate which of these reactions is likely to be exoergic, which is likely endoergic, and why? Note that only the atomic numbers are given so you must rely on your general knowledge of nuclear behavior.

$$\alpha + {}_{21}\mathrm{Sc} \rightarrow {}_{23}\mathrm{V}$$
$$\alpha + {}_{74}\mathrm{W} \rightarrow {}_{76}\mathrm{Os}$$
$$\alpha + {}_{9}\mathrm{F} \rightarrow {}_{11}\mathrm{Na}$$

3. **(25 Minutes)** Consider a point isotropic source of photons, q (*photons/sec),* in a transparent medium, located a distance, z_0 *(cm)* from an imaginary disk of radius, r_0 *(cm)*, as illustrated below. Note that the line connecting the point source to the center of the disk is normal to the plane of the disk.



   a. **(10 min)** Use integral transport theory to give an expression for the scalar flux, ϕ *(photons/cm^2-s),* as a function of radius on the disk.
   b. **(15 min)** Use integral transport theory to give an expression for the total particle flow, F *(photons/s)*, through the disk.

4. **(15 min)** A radioactive nuclide with decay constant, λ, is produced in a nuclear reactor at a constant rate of R nuclei per second. Assuming that nuclear decay is the only loss mechanism for the nuclide,

   a. **(7.5 min)** Derive an expression for the concentration of this nuclide, $N(t)$, assuming that $N = 0$ at $t = 0$.

   b. **(7.5 min)** Determine the limiting value for $N(t)$ as $t \to \infty$.

5. **(15 min)** The half-life of ^{238}U is about 4.5×10^{9} years. The half-life of ^{235}U is about 7.1×10^{8} years. Naturally-occurring uranium contains about 99.3 atom% ^{238}U and 0.7 atom% ^{235}U. Assuming no sources of either nuclide, what was the atomic fraction of ^{235}U 6 billion years ago?

6. **(25 min)** Given any quantity x, let $\pm\delta x$ denote its uncertainty. A small homogeneous sample of mass $m\pm\delta m$ with atomic mass $A\pm\delta A$ is irradiated uniformly in a constant flux $\phi\pm\delta\phi$. The total microscopic cross section for the sample material is $\sigma_t+\delta\sigma_t$. Assuming that the period of irradiation is sufficiently small to neglect depletion of the sample atoms, give an expression for the uncertainty in the *fraction* of atoms in the sample that interact during an irradiation time $T_\phi \pm \delta T_\phi$. State all assumptions.

7. **(10 minutes)** Use 1-D relativistic kinematics to show that a photon cannot undergo a photoelectric interaction with a free electron. Potentially useful formulae include:

$$E_\gamma = h\nu\ ,$$
$$p_\gamma = \frac{h\nu}{c}\ ,$$
$$E_e = T_e + m_e c^2\ ,$$
$$p_e^2 c^2 = E_e^2 - m_e^2 c^4\ .$$