1. (20 min.) The angular flux density \( \Psi(\vec{r}, \hat{\Omega}) = \phi_0 (1 - \eta^2) \), where \( \phi_0 \) is constant, and \( \theta = \cos^{-1} \eta \) is the angle between \( \hat{\Omega} \) and \( \vec{Z} \). Find: (a) the partial current density in the \( \hat{Z} \) direction, \( J^+_{\hat{Z}}(\vec{r}) \); (b) the partial current density in the \( -\hat{Z} \) direction, \( J^-_{\hat{Z}}(\vec{r}) \); (c) the net current density vector, \( \vec{J}(\vec{r}) \); (d) the total number of particles at \( \vec{r} \) per sec that cross an area \( A \) cm\(^2\) which is perpendicular to \( \hat{Z} \), and (e) the scalar flux density at \( \vec{r} \), \( \phi(\vec{r}) \).

2. (20 min.) Consider the thermal neutron radiative capture reaction with \( ^{28}\text{Si} \). Find the kinetic energy of the recoil nucleus. The mass of a proton is 1.0072765 amu. The mass of a neutron is 1.0086649 amu.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Atomic Mass (amu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ^{28}\text{Si} )</td>
<td>27.976927</td>
</tr>
<tr>
<td>( ^{29}\text{Si} )</td>
<td>28.976495</td>
</tr>
</tbody>
</table>

3. (10 min.) Neutron detectors.

(a) (50%) Identify the labeled features of the pulse height spectrum collected from a BF\(_3\) tube with thermal neutrons incident as shown below.

(b) (50%) Compare the detection mechanisms for thermal neutrons using BF\(_3\) tubes, compensated and uncompensated ion chambers, and fission chambers. Discuss the associated benefits and inherent problems of these detectors for detection of thermal neutrons.
4. (15 min.) For gamma rays passing through shielding materials, the uncollided flux decreases exponentially. Lead has the following properties: density = 11.35 g/cm³, mass attenuation coefficient = 0.125 cm²/g (for 600 keV photons). Given these properties, for a lead shield with nominal thickness of 2.0 cm having a standard error of 0.1 cm, what is the standard error of the transmitted uncollided flux for 600 keV photons?

5. (10 min.) Proportional counters filled with hydrogen at high pressure are useful for neutron spectroscopy in some situations.

(a) (50%) Describe the pulse height spectrum produced by a high pressure hydrogen proportional counter exposed to monoenergetic 1 MeV neutrons,

(b) (50%) Can such a detector be used to measure the spectrum of the neutron component of a mixed field containing 100 MeV protons? Why?

6. (20 min.)

(a) Consider a fictitious nuclide whose absorption cross section is strictly \( \frac{1}{\nu} \) at all energies. Calculate the ratio of \( \frac{I_\infty}{\sigma} \) if \( I_\infty \) is the infinitely dilute “resonance” integral for the fictitious nuclide and \( \sigma \) the value of its absorption cross section at 2200 m/sec. For the \( I_\infty \) calculation take the lower energy limit to be 0.5 eV (the value used in the chart of the nuclides).

(b) From the chart of the nuclides, it can be seen that

\[
\begin{align*}
\sigma_0 & \quad 16\text{B} & \quad 238\text{U} \\
I_\infty & \quad 1722\text{b} & \quad 277\text{b}
\end{align*}
\]

Based on these values and the result in part (a) of this question, briefly discuss the energy dependence of the absorption cross sections of \(^{16}\text{B}\) and \(^{238}\text{U}\) in the energy range above 0.5 ev.

(c) (7 min) For a pure \( \frac{1}{\nu} \) fictitious nuclide, calculate \( I_\infty \) if the lower energy limit is 0.1265 eV instead of 0.5 eV. If the “epithermal” energy range is defined as being from 0.1265 to 0.5 eV, what is the ratio of the “epithermal” to “fast” (>0.5 eV) contribution to the total infinitely dilute resonance integral?
7. (10 min.) Design of spacecraft for travel to Mars must take into account the possibility of a solar particle event bombarding the craft with a high fluence of protons in the energy range from 100 to 500 MeV.

(a) List the likely products of nuclear collisions between such protons and the atoms of a shielding material such as aluminum.

(b) As compared to the case with no shielding, what effect will these products have on the average quality factor, $Q$, after a shielding thickness equal to one mean free path of the primary radiation?

(c) If a significant fraction of an aluminum shield could be replaced by an equal mass of either lead or hydrogen, which would you recommend to reduce the dose equivalent? Why?

8. (10 min.) Electromagnetic radiation spans the energy scale from almost 0 upward. Below is a scale in terms of both wavelength and energy with certain ranges bracketed. Please name or otherwise describe the physical, atomic, molecular, or nuclear processes that produce the electromagnetic radiation associated with each of the indicated ranges. Also, what is the name commonly applied to radiation in these wavelength regimes?