1. Indicate whether the following statements are true (T) or false (F). [40 points]

( ) As the scattering angle increases for photon scattering from an electron, the wavelength of the scattered photon decreases.

( ) Radionuclides with too few neutrons for stability decay by both electron capture and positron emission.

( ) There are more different stable nuclides with an even number of protons than nuclides with an odd number of protons.

( ) The volume of a nucleus is proportional to its atomic number.

( ) The Q-value for alpha decay to an excited state of the daughter nucleus is always less than that for decay to the ground state.

( ) In all exoergic binary nuclear reactions, the reaction can occur even if the incident projectile has negligible incident kinetic energy.

( ) In a fission reaction, the lighter fission fragment has a higher initial kinetic energy than the heavier fission fragment.

( ) In a binary reaction in which a compound nucleus is formed, the reaction products depend on what nuclei came together to form the compound nucleus.

( ) A fission product decay chain always ends in a stable nuclide.

( ) The range of a 1-MeV proton is greater in aluminum than in water.

( ) In massive stars, the duration of helium burning is greater than that for hydrogen burning.

( ) A Mo cow is a hybrid bovine species developed at KSU.

( ) White dwarfs have an iron core.

( ) Pair production interactions are more likely for a 10-MeV photon than for photoelectric interactions.

( ) For the a dose of 5 rem, the radiogenic cancer hazard is greater if the dose is delivered in one hour than if the dose were received over the course of one year.

( ) A 5-MeV photon is more biologically damaging than a 5-MeV neutron.

( ) Fissile nuclides can fission if they interact with 3-MeV neutrons.

( ) In a critical reactor core operating at a thermal power of 100 W, more than $10^{13}$ fissions occur each second.

( ) The thermal fission factor depends on the relative concentration of fuel and non-fuel.

( ) Boric acid is used to vary $k_{eff}$ in a BWR.
2. Circle the designator in front of the correct answer(s) from the list following each question or statement.

(a) The mean-free-path length of 1-MeV photons in air is about [5 points]
   i. 15.7 cm
   ii. 127 m
   iii. \(2.89 \times 10^5\) cm
   iv. 0.0663 cm
   v. 137 m

(b) The water in the KSU TRIGA reactor is used as [5 points]
   i. a medium to produce the blue Cerenkov radiation
   ii. an electric insulator so core electronics do not short out
   iii. a coolant
   iv. a shield
   v. a medium to help slow fission neutrons.

(c) By lumping the fuel in a thermal reactor core [5 points]
   i. the thermal utilization factor is increased
   ii. the fast non-leakage probability decreases
   iii. the fast fission factor decreases slightly
   iv. the thermal fission factor is increased
   v. the infinite-medium multiplication factor can be increased.

(d) The uncollided flux density of gamma rays at a distance of 20 cm from a 5 kCi point source of \(^{40}\text{K}\) in water is approximately? [5 points]
   i. \(1.25 \times 10^9\) cm\(^{-2}\) s\(^{-1}\)
   ii. \(3.67 \times 10^{10}\) cm\(^{-2}\) s\(^{-1}\)
   iii. \(1.16 \times 10^{10}\) cm\(^{-2}\) s\(^{-1}\)
   iv. \(3.93 \times 10^9\) cm\(^{-2}\) s\(^{-1}\)
   v. \(3.07 \times 10^{10}\) cm\(^{-2}\) s\(^{-1}\)

(e) The tissue dose rate produced by the source in the previous problem 20 cm from the source is
   i. 1.7 rad/s
   ii. \(5.7 \times 10^{-3}\) Gy/s
   iii. 2.6 rad/s
   iv. 0.083 Gy/s
   v. 30 rad/h

(f) Uranium fuel 20 atom-% enriched in \(^{235}\text{U}\) has a \(N^{235}/N^{238}\) atomic density ratio of [5 points]
   i. 0.20
   ii. 0.25
   iii. 0.3
   iv. 0.4
   v. 0.987
(g) Consider a bare, homogeneous, spherical, source-free, critical reactor operating at a steady-state power $P_o$. Which of the following will happen if the core is deformed into the shape of a football? [5 points]

i. nothing
ii. the reactor becomes subcritical
iii. $k_{\infty}$ remains unchanged
iv. the power increases exponentially
v. the power will level out at a new steady-state power
vi. the power decreases

(h) During the handling of a radioactive $^{60}\text{Co}$ source, a worker receives an accidental whole body dose of 30 rem. The expected subsequent deterministic radiation effects include

i. the likely formation of cataracts
ii. vomiting
iii. decrease in white cell counts
iv. erythema
v. no deterministic effects are likely

(i) The same worker in the above problem is a male of age 25. What is the probability he will eventually die of leukemia as a result of this accident? [5 points]

i. 0.59%
ii. 0.015%
iii. 0.018%
iv. 0.46%
v. 0.38

(j) Although other countries reprocess their spent nuclear fuel, the U.S. has decided not to reprocess its spent fuel. The reason for this is: [5 points]

i. It is cheaper to buy reprocessed plutonium from the French than to construct US reprocessing facilities.
ii. In the US all the fissile material is consumed before the fuel is removed from a reactor.
iii. By separating plutonium, there would be an increased risk of plutonium theft.
iv. After building the Yucca mountain waste repository, they need spent fuel to store.
v. Reprocessing spent fuel would produced too much radioactive waste.

(k) Which of the following radiations leave a commercial x-ray tube? [5 points]

i. characteristic fluorescent x rays
ii. bremsstrahlung
iii. Auger electrons
iv. photoelectrons
v. Compton scattered photons
vi. annihilation photons

(l) A 1-gram sample of $^{239}\text{Pu}$ is uniformly irradiated by a flux of thermal neutrons $\phi = 10^8$ cm$^{-2}$s$^{-1}$. The rate of fission fragment production in this sample is [5 points]

i. $3.8 \times 10^8$ s$^{-1}$
ii. $1.9 \times 10^8$ s$^{-1}$
iii. $5.2 \times 10^8$ s$^{-1}$
iv. $1.2 \times 10^8$ s$^{-1}$
v. $1.8 \times 10^{32}$ s$^{-1}$
3. Consider a beam of protons bombarding a sample of silicon. One possible reaction is \( ^{28}\text{Si}(p,\alpha)^{25}\text{Al} \).

(a) Calculate the Q-value for this reaction. \([10 \text{ points}]\)

(b) Calculate the kinematic threshold for the reaction. \([5 \text{ points}]\)

(c) Calculate the Coulombic threshold for the reaction. \([5 \text{ points}]\)

(d) What is the minimum energy that a proton must have in order for the reaction to occur? \([5 \text{ points}]\)

(e) What is the minimum kinetic energies of the products of the reaction? \([5 \text{ points}]\)
4. A broad monoenergetic parallel beam of 1.5-MeV $\gamma$ rays is normally incident on a concrete wall. The incident dose rate is 125 Sv/h. How thick must the wall be to reduce the uncollided dose rate at the backside of the wall to 1 mSv/h? [15 points]

5. A radioactive tracer, with a half-life of 55 days, is injected into an underground aquifer. Eighty-five days later the radioisotope is first observed in a monitoring well 500 m downstream from the injection site. What is the speed (m/s) of water flowing between the injection site and the monitoring well? [15 points]