Exercise 2: RADIOACTIVE ISOTOPES.

2.1. General concepts.

The students must familiarize themselves with the processes of radioactive decay (primarily emissions of alpha, beta and gamma particles, as well as the characteristics regarding their energy and penetration capabilities), the laws governing the loss of activity, and the effects radiation causes in their interaction with materials (ionization and/or excitation). The contents from chapter 1 of the text by **García Segura y colaboradores (Ed. Síntesis, 1996)** are sufficient for this purpose.

2.2. Guided visit to a radioactive facility.

2.2.1. Introduction

A radioactive research facility is a physical space enabled for working safely with radioactive isotopes. The radioactive facility's safety is guaranteed by the supervision of an individual authorized by the Consejo de Seguridad Nuclear (Nuclear Safety Council). This institution is responsible for inspecting the operations and conditions at the radioactive facility at least once a year.

There are two radioactive facilities at the UMH; the first is IRA-1392, located on the San Juan Campus, and the second is IRA-2882, on the Elche campus. The visit will take place at the Elche facility, and the meeting point for this is the entrance to the Torrepinet building on the date and time set for this activity.

2.2.2. Basic concepts.

To make the most of this visit, the student will become familiar with the types of radioactive decay, the concept and units of measurement of the decay of radioactive isotopes, as well as the basic functions of measuring instruments used to detect ionizing radiation.

Some recommended materials to bring along for this include a notebook and writing instruments.

2.2.3. Regulations to follow during the visit.

Although the handling of radioactive sources, utilized in exempt quantities, will be performed by the facility supervisor, some regulations exist concerning student behavior during the visit: lab coats are to be worn, and prohibited activities include eating, drinking, applying makeup and smoking, in addition to engaging in any activity that may compromise the facility's safety.

2.2.4. Visit Objectives.

1. The student will comprehend the structural characteristics of a radioactive facility concerning safety.
2. The student will comprehend the use of personal dosimeters as a basic element in radiological protection.

3. The student will test the principals of radioprotection (time, distance and shielding) by handling a Geiger-Müller detector.
4. The student will experiment with different penetration in materials by alpha and beta particles, and will deduce the equation regulating the calculation of a shield.
5. The student will make a distinction between different measuring instruments (particle counters) for beta and gamma radiation in a scientific experiment.
6. The student will comprehend the problems resulting from ionizing radiation in a scientific experiment by conducting the "quenching" test.

2.3. Examples of numeric problems related with radioactive isotopes.

2.3.1. Determination of the activity.

Two radioactive samples are used here. One of them is marked by an isotope that decays exclusively by emitting high-energy **alpha** particles with values oscillating within a very narrow margin of around 4 meV. The other isotope is exclusively a **beta** emitter having moderate energy values around a wide range that varies between 1 and 20 keV. Would it be sufficient to determine the radioactivity of both samples with a liquid scintillation counter? And what about a solid scintillation counter? Reason your response.

2.3.2. Preparation of solutions containing radioactive isotopes.

Start with an unmarked glucose (solid) and a stock glucose solution marked with C^{14} at a concentration of 10^{-2} M and specific activity of 0.02 microCi/ml. Describe how to prepare 50 ml of a glucose solution having a concentration of 10^{-3} M and activity of 3000 cpm/micromol. One microCi is equivalent to 2.22×10^{6} cpm.

2.3.3. Presence of radioactive isotopes in nature.

Many radioactive isotopes are produced continually and naturally in nature, and these account for a specific percentage (natural abundance) in the collection of stable or unstable isotopes for a given element. For example, carbon-14 is continually produced in high atmospheric layers due to the bombardment of nitrogen-14 by neutrons present in cosmic radiation.

The reaction is this: ${}_{7}N^{14} + {}_{0}n^{1} \rightarrow {}_{6}C^{14} + {}_{1}H^{1}$.

Consequently, the carbon compounds being synthesized by living beings contain 13 dpm/g of carbon. When this being dies, it stops incorporating radioactive carbon, and that which he/she already possesses begins to decay with a half-life of 5,700 years. This radioactive carbon decay of carbon-14 is frequently used for dating remains having ages between approximately 5,000 and 20,000 years (i.e., between one and four or five half-lives), like the following exercise illustrates:

Calculate the approximate age of a biological fossil material presenting carbon-14 activity equal to 3 dpm/g of carbon.

Another well-known example of the presence of a natural radioactive isotope is potassium-40. This exists naturally in relatively high abundance, and a result of this is that the majority of glass that is produced from silicates of several elements, including potassium, is sufficiently radioactive so that glass vials employed in radioactive determinations must be "low potassium" glass in order to avoid baseline levels of radiation that are too high. Another result of this is that all living organisms possess significant potassium-40 radioactive levels, which is illustrated in the following problem:

Potassium-40 ($t_{1/2}$ = 1.3 x 10^9 years) comprises 0.012% of the potassium present in nature. Potassium makes up approximately 0.35% of a human's total body weight. Calculate the total radioactivity from potassium-40 in an individual weighing 75 Kg.

2.3.4. Isotropic dilution.

Ten milliliters of a suspended erythrocyte marked with Cr^{51} having total radioactivity of 3 x 10^8 cpm is injected intravenously into a large experimentation animal. A blood sample is taken 10 minutes after the injection, and its activity is determined to be 5x10^4 cpm/ml. What is the animal's volume of blood? What precautions must be taken if the radioactive isotope in question had a very short half-life?

2.3.5. The use of isotopes in marking other molecules.

1.7 mg of a purified enzyme (molecular mass 55,000) is incubated with excess iodocetamide-C^{14}, a reagent specific to sulfhydryl groups, with a specific activity of 2 microCi/milimol. The resulting carboxymethylated protein is precipitated, the excess free iodoacetamide washed, it is dissolved in a small quantity of buffer and all its activity is measured in a liquid scintillation counter that is 80% efficient. After counting for one hour, 13,190 counts are registered above the background noise. Determine the number of free sulfhydryl groups per enzyme molecule. One microCI is equivalent to 2.22 x 10^6 cpm. Can the same result be expected if the protein had been reduced with reagents like dithiothreitol or mercaptoethanol before the reaction with iodoacetamide?

2.4. Article/commentary regarding the accident at the Fukushima nuclear power plant.

Fallout at Fukushima

What risks does Japan face as a result of radiation leakage from the nuclear power plant hit by the recent earthquake and tsunami? [Original site]

Technicians in Japan struggle to contain breeches in cooling and containment apparatuses at the Fukushima Daiichi nuclear reactor in eastern Japan, which was hit by the massive earthquake and subsequent tsunami on March 11th. Though considerable uncertainty remains concerning the exact amount of radioactive material that has leaked from the facility thus far, low level radiation has turned up in crops grown in the vicinity of the plant, and the danger of a widespread catastrophe lingers. This week, The Scientist examines the latest research on the effects of radiation and explores some of the worst-case-scenario health and environmental effects of a nuclear disaster in Japan.

The acute effects of radiation

Late last week, a skeleton crew of about 50 workers at the Fukushima Daiichi plant was urgently attempting to cool the reactor core, as specially-fitted helicopters tried (and failed) to drop tons of seawater on the failing facility. Early this week, reports from Japan indicated that the last workers trying to save the facility from catastrophe evacuated as smoke billowed from two of the reactor units. Radiation levels currently being reported by Japanese officials are still quite low, and the early public evacuation reduced the concern for community health risks, said William Schull, emeritus professor at the University of Texas Health Science Center in Houston and an expert on the health effects of the atomic bombs dropped on Hiroshima and Nagasaki in the 1940s. But the workers at the nuclear plants still risked acute radiation exposure and serious health problems as a result, he added.

Upon direct exposure to ionizing radiation, anemia -- the loss of red blood cells -- and leucopenia -- the loss of white blood cells such as those important in fighting off infection -- can result, increasing susceptibility to disease. In addition, someone directly exposed to radiation may display other symptoms of acute radiation syndrome (ARS), such as vomiting, diarrhea, excessive bleeding brought on from the death of hematopoietic stem cells in bone marrow, and hair loss. Such symptoms, however, are caused by exposure of 1-10 grays (Gy), a unit of absorbed radiation dose. The doses of radiation leaking from the Japanese reactor are far below this: On Saturday, Japanese news outlet NHK News reported that the plant's operator, Tokyo Electric Power Company, detected radioisotope iodine 131 at about 5.9 milibecquerels per cubic centimeter, or about 0.0003 Gy/hour. (Click here for an infographic comparing the radiation dose absorbed by humans engaged in various activities.)

But "things could quickly worsen," Schull said. If radiation continues to seep from the reactor, officials could use a recently devised classification system to assess the health of those exposed. The Radiation Injury Severity Classification (RISC) system estimates three sets of clinical and haematological parameters to calculate "a combined score [that] gives you a pretty accurate estimate of what's going to happen to this person," said University of Pittsburgh biostatistician Richard Day, who collaborated in the creation of RISC. Applying the system to 59 workers in a Russian nuclear fuel production facility, Day, Niel Wald of the University of Pittsburgh, and coauthors estimated threshold values for some ARS symptoms, including vomiting (~1.5 Gy), severely low white blood cell count (~3.5 Gy), and mortality (~6-7 Gy).

"In the roughly 115 years since Roentgen discovered X-rays we have learned a lot about the values and hazards of exposure to ionizing radiation," Schull said. "But we still have a hell of a lot to learn."

-- Bob Grant

Radiation and the immune system

Although most cells in the body can withstand considerable doses of radiation before dying, immune cells begin to react at even small doses of radiation. While recent reports suggest that the workers at the Fukushima Daiichi plant have so far only been exposed to relatively low levels of radiation, their exposure could trigger immunological reactions -- though depending on the dose, not all of them may be harmful.

According to several reports, workers at the Fukushima plant have been exposed to radiation levels ranging from 200-400 millisieverts (mSv, a measure of radiation absorbed by a person) per hour -- levels that the human body can withstand with minimal damage, said Richard Wakeford, visiting epidemiology professor at the Dalton Nuclear Institute of the University of Manchester. Once doses reach levels of 500 mSv or more, however, the number of lymphocytes, white blood cells involved in immune response, is cut by half within a few days, and there is considerable damage to stem cells in the bone marrow, said Yoichiro Kusunoki, chief of the department of radiobiology and molecular epidemiology at the Radiation Effects Research Foundation in Hiroshima, Japan, in an email.

At high doses, these effects can be long lasting. According to studies of atomic bomb survivors, T-cells never fully recover, neither in number nor effectiveness, although stem cells and other immune cells bounce back to normal levels in about two months. The body compensates for these shortfalls by increasing levels of inflammatory cytokines -- a pattern that resembles the immune systems of the elderly, suggesting that the immune system may age more rapidly after radiation exposure.

But the production of inflammatory cytokines can be seen even at "a relatively low dose (several mSv) that does not trigger apoptosis of any types of cells," added Kusunoki. This short term inflammation could initially be protective by helping clear cells damaged by the radiation. However, researchers studying radiation exposure during cancer radiation therapy suggest that low doses of radiation that trigger inflammation could also initiate the kind of chronic inflammation that leads to cancer.

2.5. Evaluation.

Each student will be asked to a produce a text document using Word for Windows 2003/2007/2010 from the Microsoft office package, showing the results and the development followed to obtain them, from sections **2.3.1.**, **2.3.2.**, **2.3.3.**, **2.3.4.**, and **2.3.5.**

2.6. Handing in the work.

Each student must hand in a *doc* file (NO OTHER FORMAT WILL BE ACCEPTED) containing the aforementioned material requested. This file must be named in a manner using the student's name and first surname followed by "_2". For example, *I am student Emilio Moreno Serrano, and I will produce the file: MorenoSerrano_Emilio**_2.doc***.

These 3 files are to be turned in **TOGETHER AS A SINGLE PACKAGE** via the **HOMEWORK** system the students have personal access to on the course webpage.

Only exercise reports sent via the email account each student has through the UMH will be accepted.