Contents

12.1 Introduction

FDA's Winchester Engineering and Analytical Center specializes in radioactivity analyses.

FDA has monitored radionuclides as part of its food safety efforts for over fifty years.

The Public's concern about health risks due to radionuclide contamination has increased as a result of the nuclear accidents at Three Mile Island (March, 1979) and Chernobyl (April, 1986) and (Fukushima, April 2011). FDA's Center for Safety and Applied Nutrition coordinates and oversees several food programs. The Radionuclides in Foods program includes a domestic program – samples collected near nuclear power plans and the total diet program; an import program - import foods collected from countries most likely to have food products with radionuclide contamination.

The "Total Diet Study" (TDS) was initiated in the early 1960s to monitor possible contamination of foods by radionuclides resulting from atmospheric nuclear tests. The foods tested in the program represent the general US food supply and the American diet.

FDA's Center for Drug and Evaluation coordinate the radiopharmaceutical program. Radiopharmaceuticals are an extension of the Pharmaceutical Program. USP as well as NDA/ANDA methodology is utilized to indicate conformance to specifications.

Though atmospheric nuclear tests are now rare and are banned by many countries, other potential sources of radionuclide contamination exist. WEAC maintains readiness for Radiological Emergency Response for foods, drugs and medical devices. WEAC will provide analytical testing as well as personnel dosimetry badges and monitoring.

12.2 Radiation Safety

A. Objective

To familiarize the trainee with the safety issues inherent within the radionuclide section's activities. All new hires are given basic radiation safety training covering the following topics: radiation exposure to man, sources of radiation, biological effects of radiation, radiation protection guides, and safety.

The Basic Radiation Safety Course, a more comprehensive study than the new-hire course, covers the topics found in Section 12.2.B.

B. Assignment

The Basic Radiation Safety Course, offered to scientists and investigators, includes the following:

1. *Radiation Exposure to Man*
   Identification of natural and man-made sources of radiation and their contribution to background radiation levels are discussed.

2. *Review of atomic structure and radioactivity*
   The basic structure of the atom, atomic nomenclature, units of nuclear mass and energy, the definition of an element and isotope are discussed. The types of radioactive emissions (including alpha particles, beta particles, gamma rays) are defined.

3. *Interaction of radiation with matter*
   Charged particles interactions (ionization, excitation and *bremsstrahlung*), photon interactions with atoms are discussed.

4. *Units of Radioactivity and Radiation*
   Radioactive decay, the rate of radioactive decay (half-life), and units used to measure decay rate are defined.

5. *Correlation of Units of Activity, Exposure, and Biological Effects*
   Units of measure for radioactivity, exposure, dose, and dose rate are defined. Problem solving exercises demonstrate the calculation of exposure rate resulting from an external source of radioactive material. The biological effects (somatic and genetic effects, acute and chronic effects, and threshold and non-threshold effects) are discussed.

6. *Basic Principles of Radiation Detection Instruments, Personnel Monitoring and Radiation Survey Instruments*
   Instruments that measure the presence of radiation include personnel monitoring instruments, survey instruments, and laboratory instruments. The instrument's theory of operation and its applications are discussed. See Section 12.3 for "Laboratory Instruments for Radioactivity Measurement."

7. *Radiation Protection Guides and Dose Limits*
   Radiation protection guides, the "as low as reasonably achievable" (ALARA) principle, and dose limits are discussed. The Nuclear Regulatory Commission, Agreement States, and the Environmental Protection Agency are the principal guide limit authorities.

8. *Principles of Radiation Protection*
   The basic principles of protecting personnel from ionizing radiation will depend upon the type and energy of radiation, and intensity and location of the source. External radiation hazards are controlled through time, distance, and shielding. Contamination control (containment and cleanliness) prevents internal radiation exposure. The purpose of surveys is discussed.

9. *Regulatory Issues:*
   Management of Radioactive Wastes
      The regulations pertaining to the management of radioactive waste are provided by NRC in Title 10, Part 20 (Energy) of the Code of Federal Regulations (CFR).
   Transportation of Radioactive Materials
      The regulations pertaining to the transportation of radioactive materials are provided by NRC in Title 10, Part 20, and also Title 49 (Transportation) of the CFR.
   Receiving of Radioactive Packages

A model procedure is found in the U. S. Nuclear Regulatory Commission's Regulatory Guide10.8, Appendix L.

C. Questions

1. Define the term "atom." Explain what the "A" & "Z" numbers of an isotope represent.

2. Discuss the characteristics of alpha-particle decay, beta-particle decay, gamma-ray and x-ray emission. Which types of radiation have an electrical charge? Discuss the difference between x-ray and gamma ray emission.

3. Define "ionization."

4. Describe the three ways in which photons interact with atoms.

5. What is the difference between genetic and somatic effects of ionizing radiation?

6. Define the threshold theory and the linear non-threshold theory.

7. Describe the principal types of personal dosimetry; discuss the use of control badges. What is found in the WEAC Radiation Safety Program for personal dosimetry?

8. Define the three methods used for minimizing radiation exposure.

9. Define "survey." What type of surveys are found in the WEAC Radiation Safety Program?

10. Describe how requests for radioactive standards are purchased at WEAC.

11. Describe how packages are screened for radioactivity at WEAC.

D. References

1. U.S. Food and Drug Administration (current edition). RH102 FDA Basic radiation safety course resource manual

2. U.S. Food and Drug Administration, (current edition) ORA Radiation Safety Manual SOP

3. U.S. Food and Drug Administration, (current edition) Winchester Engineering and Analytical Center Radiation Safety Manual SOP

4. Friedlander, G., Kennedy, J., Macias, E., Miller, J. (1981). *Nuclear and radiochemistry* (3rd ed.). New York: John Wiley & Sons.

12.3 Laboratory Radiation Detection Instrumentation

A. Objective

To familiarize the trainee with the radionuclide laboratory equipment.

B. Assignment

The trainer will discuss the location, care, and calibration procedures for equipment found in the radionuclide laboratory. The training exercises include calibration of the instruments defined below.

Typical equipment found in the radionuclide laboratory may include the following:

1. low level gas-flow proportional counter,
2. low background beta counter,
3. liquid scintillation counter,
4. alpha spectrophotometer,
5. ionization chamber,
6. solid state silicon surface barrier detector,
7. high purity germanium detector,
8. sodium iodide detector
9. ICP Mass Spectrometer , and
10. x-ray detector.

C. Questions

1. Describe the theory of operation and its application in the laboratory for the following: a proportional counter, a scintillation counter, and a solid state detector coupled to a multichannel analyzer.

D. References

1. U.S. Food and Drug Administration (current edition). RH102 FDA Basic radiation safety course resource manual

2. US Food and Drug Administration (current edition) ORA Radiation Safety Manual SOP.

3. US. Food and Drug Administration, (current edition) Winchester Engineering and Analytical Center Radiation Safety Manual SOP

4. Friedlander, G., Kennedy, J., Macias, E., Miller, J. (1981). *Nuclear and radiochemistry* (3rd ed.). New York: John Wiley & Son

5. Dean, J. *Analytical chemistry handbook* (1st ed.). New York: McGraw-Hill, Inc.

12.4. Radionuclides in Foods Program

A. Objective

The trainer will provide the training in various methodologies as described in the training SOP, e.g. reading, demonstrations, self-study, on the job training.

B. Assignment

Gamma-emitting radionuclides and Strontium 90

Training samples may be reserved food samples (e.g. dried mushrooms, jam, leafy vegetables) or proficiency samples. Initial training covers analyses of analyses of gamma emitting radionuclides and Strontium 90.

The food program may include, but not limited to, the following training assignments:
1. Tritium
2. Gross alpha
3. Gross beta
4. Plutonium 238, 239

C. Questions

1. What is the purpose for using the 400 mL fill line in analysis of gamma emitting

radionuclides?

2. Describe the separation methods utilized for Sr-89/90 in the Market Basket Analysis of Strontium 90 method.

3. Describe the sample preparation for the analysis of tritium by liquid scintillation analysis.

D. Methodology References

1. International Atomic Energy Agency. (1989). Technical Report Series Publication 295.

2. Cunningham, W. C., Anderson, D. L., and Baratta, E. J. (1994). Radionuclides in domestic and imported foods in the United States, 1987-1992. *Journal of AOAC International*, 77(6)**,** 1422-1427.

3. Capar, S. G., and Cunningham, W. C. (2000). Element and radionuclide concentrations in food: FDA total diet study, 1991 – 1996. *Journal of AOAC International*, *83*(1) 157-177.

4. Horowitz, W. (Ed.). (current ed.). *AOAC official methods of analysis* (Chap. 13, Radioactivity). Gaithersburg, MD: AOAC International.

5. U.S. Department of Energy. (1979). *Environmental measurements laboratory: procedures manual* (HASL-300, Rev. 1992). New York: U.S. Department of Commerce.

6. U.S. Environmental Protection Agency. (1979). *Radiochemical analytical procedures for analysis of environmental samples*, EMSL-LV-0539 – 17. Las Vegas, NV: U.S. Government Printing Office.

7. American Public Health Association. *Standard examination for the examination of water and wastewater* (20th ed., Pt. 7000, Radioactivity). Washington, DC: American Public Health Association.

8. Baratta, E. J. and Reavey, T. C. (1969, November.-December). Rapid determination of strontium90 in tissue, food, biota, and other environmental media by tributyl phosphate. *Journal of Agricultural and Food Chemistry*, *17*(6), 1337-1339.

9. Apidianakis, J.C. (2000) *Determination of strontium-90 in foods*. A compilation of unpublished, validated methods and adaptations by this author**.**

10. Douglas, G. S. (Ed.). (1967). *Radioassay procedures for environmental samples* (Public Health Service Publication No. 999-RH-27, Ashing Procedures). Washington DC: U.S. Government Printing Office.

11. Mango, P. J., Bratta, E., Ferri, E. (1964). *Northeast Radiological Health Laboratory, analysis of environmental samples, chemical and radiochemical procedures* (NERHL-64-1). Winchester, MA: U.S. Government Printing Office.

12. Troianello, E.J. (1978, October 18). Dehydration of food samples for assay of tritium in free water. *Laboratory Information Bulletin,* No. 1913.

13. Lumsden, E., Baratta, E. (1977, January 31). Isotopic determination of Pu in food ash. *Laboratory Information Bulletin*, No. 2015.

12.5 Radiopharmaceutical Program

A. Objectives

The trainer will provide the training, e.g. reading, demonstrations, self-study, on the job training. Assigned radiopharmaceuticals will be dependent on Center/CDER initiatives or requests.

B. Assignment

The trainee will read the ORA Laboratory Manual, Volume IV, Section 3: Drug Analysis.

The USP/NDA methods for radiopharmaceuticals include conventional pharmaceutical analyses and may include the following:

1. assay for radioactivity,
2. radiochemical purity,
3. radionuclidic purity, and
4. radionuclide identification.

C. Questions

1. Define radiochemical purity and radionuclidic purity.

2. Define the term "cold kit." Define precautions are to be taken when preparing a cold kit with Tc-99m? What happens when air is inadvertently introduced into the cold kit?

3. Discuss the theory of operation and use of Tc-99m/Mo-99 generator.

D. References

1. *United States pharmacopoeia and national formulary* (current ed.).

2. *ORA Laboratory Manual*, Volume IV, Section 3: Drug Analysis.

12.6 Answer Key

12.2 Radiation Safety

1. **Define the term "atom."** An atom is the smallest component of an element having the properties of that element. An atom consists of a central nucleus, comprised of positively charged protons and uncharged neutrons, surrounded by negatively charged electrons. The number of protons in the nucleus of the atom determines the identity of the element. The atomic mass number, **A**, is equal to the sum of the number of protons, **Z**, plus the number of neutrons, N, in the nucleus.

2. **Discuss the characteristics of alpha-particle decay, beta-particle decay, and gamma-ray and x-ray emission. Which types of radiation have an electrical charge? Discuss the difference between x-ray and gamma-ray emission.** Alpha-particle decay is characterized by the emission of a highly energetic helium nucleus, or alpha particle, from the nucleus of a radioactive isotope, resulting in the transformation of the isotope to one whose nucleus contains two fewer protons and two fewer neutrons. Beta-particle decay is characterized by the ejection of an ordinary electron from the nucleus of a radioactive isotope, resulting in the transformation of a neutron into a proton in the nucleus. Positron decay, sometimes called beta-plus decay, is characterized by the ejection of a positively charged electron from the nucleus, resulting in the transformation of a proton into a neutron in the nucleus. Gamma rays and x-rays are electromagnetic radiation emitted by atoms following radioactive transformation. Alpha and beta particles and positrons carry charge; gamma and x-rays are uncharged. X-rays and gamma rays are electromagnetic radiation; x-rays originate in the extra nuclear structure of atoms and gamma rays originate in the nuclei of atoms.

3. **Define "ionization."** Ionization is the process of removing an atomic electron from the electric field of the nucleus, resulting in an ion pair consisting of the remaining positively charged atom and the negatively charged electron.

4. **Describe the three ways in which photons interact with atoms.** Photons interact with matter primarily via the following mechanisms: photoelectric effect, Compton Effect, and pair production. In the photoelectric effect, a photon interacts with an atomic electron, resulting in the emission of an electron having energy equal to that of the incident photon minus the binding energy of the electron. The incident photon disappears. In the Compton Effect, a photon collides with an electron resulting in a scattered photon and a scattered electron. The scattered photon has less energy than that of the incident photon, and the difference between the incident and scattered energy of the photon is transferred to the scattered electron. In pair production, a photon of energy greater than 1.02 MeV spontaneously disappears as it passes near a nucleus, resulting in the production of an electron and a positron (an electron-positron pair).

5. **What is the difference between genetic and somatic effects of ionizing radiation?** Genetic effects are those that occur in the descendants of a parent whose DNA molecules are modified due to exposure to ionizing radiation. Somatic effects are those which occur in the exposed individual. Genetic effects may affect subsequent unexposed generations; somatic effects are limited to the exposed individual.

6. **Define the threshold theory and the linear non-threshold theory.** The threshold theory of dose response is used to describe radiation effects that occur only after a minimum, or threshold, dose has been received. The magnitude of the effect increases with the dose received, and there is a clear causal relationship between radiation exposure and the observed effect. The linear non-threshold theory is used to describe the frequency of occurrence of a defined radiation effect as a function of dose received by an exposed population. The plot of frequency of response vs. dose is linear and passes through the origin of the plot.

7. **Describe three types of personal dosimeters worn by individuals for personnel monitoring; discuss the use of control badges.** Personal dosimeters are devices worn by individuals to measure radiation exposure. Three types of personal dosimeters are: pocket meters, film badges, and thermoluminescent dosimeter (TLD) badges. Pocket meters are generally based on an air wall ionization chamber and can either be of the "direct reading" type, where the dose may be read from a scale or other indicator on the device, or the "indirect reading" type, where an instrument is needed to read the dose. Film badges consist of one or more small sheets of photographic film enclosed in a light-tight container that may be affixed to clothing. The exposed film is developed to obtain the radiation dose. TLD badges contain thermoluminescent crystals that absorb and store energy when exposed to radiation, and emit light when heated. The light output is proportional to the radiation dose. The dose is read by heating the TLD crystal in a device equipped to detect the emitted light. Control badge readings are used to correct personal dosimeter readings to more accurately

reflect the exposure received by individuals working with radiation. Control badges are generally maintained in an area remote from radiation areas but under similar environmental conditions as those where personal dosimeters are worn. See ORA Radiation SOP – TLD Program for information about the ORA TLD program.

8. **Define the three methods used for minimizing radiation exposure.** Radiation exposure may be limited by minimizing the time or duration of exposure, by maximizing the distance between the radiation source and the exposed individual, and by maximizing the shielding between the source and the exposed individual.

9. **Define "survey."** A survey is an evaluation of radiological conditions to determine the presence of surface or airborne contamination, unknown sources, or dose rate in the area. See WEAC Radiation Safety Manual for information describing WEAC survey program.

10. See WEAC Radiation Safety Manual for the procedure for purchasing standards.

11. See WEAC Radiation Safety Manual the procedure for screening packages for radioactivity.

12.3 WEAC Laboratory Radiation Detection Instrumentation

1. **Describe the theory of operation and its application in the laboratory for the following: a proportional counter, a scintillation counter, and a solid state detector coupled to a multichannel analyzer.** A proportional counter consists of a gas-filled chamber containing two electrodes across which an electrical potential is applied. Under the influence of the electric field, ions generated by radiation in the gas are collected, producing an output signal proportional to the energy deposited in the counter by the radiation. Therefore particle identification and energy measurement are possible for any charged particle. A scintillation counter consists of a medium that produces light when ionizing radiation passes through it, and a detector, usually a photomultiplier tube, which amplifies the light and produces an output signal. The scintillator may be solid, liquid, or gas. Photons, neutrons, and charged particles may be detected using scintillation counters. A solid state detector consists of a semiconductor crystal across which a bias voltage is applied. Charges generated in the crystal by radiation are collected and produce a voltage pulse proportional to the energy deposited in the crystal. The pulse-height distribution or spectrum may displayed using a multichannel analyzer (MCA) and consists of a plot of counts versus energy.

12.4 Radionuclides in Foods Program

1. **What is the purpose for using the 400-mL fill line in the analysis of gamma-emitting radionuclides?** The 400-mL fill line is the level to which a plastic sample container is filled in order to maintain a constant geometry for all samples counted on the detector. The detector is also calibrated using a radioactive source in an identical plastic container filled to the 400-mL line.

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2. **Describe the separation methods utilized for Sr-90 in the Market Basket Strontium 90 method.** In this method the activity of Y-90, the decay product of Sr-90 present in radioactive secular equilibrium with Sr-90 in the sample, is measured. A known quantity of food homogenate is dried and charred at high temperature, and the ash is dissolved in nitric acid. The acid solution is shaken in a separatory funnel with tributylphosphate and strontium and yttrium carrier solutions. Y-90 is differentially dissolved (or separated from Sr-90) in the organic phase. After a series of procedures, Y-90 as oxalate is deposited onto a paper filter, and assayed using a beta particle counter. The Y-90 activity is then used to calculate the Sr-90 activity in the original food sample.

3. **Describe the sample preparation for the analysis of tritium by liquid scintillation analysis.** A weighed, edible portion of sample is transferred to a special glass distillation tube. An identical tube, used as a water trap, is joined to this tube and to a vacuum pump via an adapter. The sample tube is sealed and mildly heated, and the water trap is evacuated using the pump, and chilled. The two tubes are then joined together via the adapter and water vapor from the sample is gradually collected in the cold trap. The collected water is then mixed with liquid scintillator solution (sometimes referred to as a "cocktail") which produces visible light when ionizing radiation (emitted by tritium) passes through it. The light pulses are detected and counted in the liquid scintillation counter.

12.5 Radiopharmaceutical Program

1. **Define radiochemical purity and radionuclidic purity.** Radiochemical purity is the degree to which a radioactive compound is free of chemical contaminants. Radionuclidic purity is the degree to which a radioactive substance is free of radionuclides other than those declared.

2. **Define the term "cold kit." What precautions are to be taken when preparing a cold kit with Tc-99m? What happens when air is inadvertently introduced into the cold kit?** A "cold kit" is a compound or complex that is combined, or reconstituted, with Tc-99m resulting in a radioactive pharmaceutical. The compound is usually contained in a septum-

sealed vial into which sodium pertechnetate solution may be injected by syringe. The vial may also be under vacuum or contain an inert gas. Procedures for reconstituting the kit are specified in the labeling. Precautions to prevent the accidental introduction of air while adding the pertechnetate solution may be neededd. Air inadvertently introduced into the vial may react with reducing agents or other chemicals in the vial resulting in the production of radiochemical impurities in the drug.

3. **Discuss the theory of operation and use of a Tc-99m/Mo-99 generator.** A Tc-99m/Mo-99 generator contains Mo-99 fixed on an alumina column. Tc-99m, the decay product of Mo-99, is removed, or eluted, from the generator by passing a saline solution through the column, resulting in a sodium pertechnetate solution. The pertechnetate solution may be used to reconstitute cold kits.

12.7 Document Change History

Version 1.2 Revision Approved: 02-06-12 Author: LMEB Approver: LMEB

Version 1.2 changes:
Table of Contents – deleted Quality Assurance/Quality Control; added Document History
Section12.1 Introduction – revised
Section 12.2 C. – Questions 7. and 9. revised; added 10. and 11.
Section 12.2 D. – References 1. and 2. updated; added WEAC Radiation Safety Manual SOP
Section 12.3 B. – Bullets 1,, 2., and 5. revised; added ICPMS
Section 12.3 C. – deleted 2.
Section 12.3 D. – updated 1. and 2.; added WEAC Radiation Safety Manual SOP
Section 12.4 A. and B. – revised
Section 12.4 C. - deleted 2. and 5.
Section 12.4 D. – updated 9.
Section 12.5 A. and B. – revised
Section 12.5 C. – updated 9.
Section 12.6 – deleted
Section 12.7 Answer Key (now 12.6) – added 10. and 11. to 12.2; deleted 2. from 12.3; deleted 2. and 5. from 12.4; deleted 12.6