MODULE 2.0: RADIOLOGICAL AND CHEMICAL PROPERTIES OF URANIUM

Introduction

Welcome to Module 2.0 of the General Health Physics Practices for Fuel Cycle Facilities Directed Self-Study Course! This is the second of seven modules in this self-study course. The purpose of this module is to assist the trainee in recognizing basic chemical, physical, and radiological properties of uranium and other radioactive materials present at fuel cycle facilities that are associated with the health physics program. This self-study module is designed to assist you in accomplishing the learning objectives listed at the beginning of the module. There are six learning objectives in this module. The module has self-check questions and an activity to help you assess your understanding of the concepts presented in the module.

Before You Begin

It is recommended that you have access to the following materials:

- Trainee Guide

Complete the following prerequisites:

- Module 1.0 Health Physics Fundamentals

How to Complete this Module

1. Review the learning objectives.
2. Read each section within the module in sequential order.
3. Complete the self-check questions and activities within this module.
4. Check off the tracking form as you complete the self-check questions and/or activity within the module.
5. Contact your administrator as prompted for a progress review meeting.
6. Contact your administrator as prompted for any additional materials and/or specific assignments.
7. Complete all assignments related to this module. If no other materials or assignments are given to you by your administrator, you have completed this module.
8. Ensure that you and your administrator have dated and initialed your progress on the tracking form.
9. Go to the next assigned module.

This page intentionally left blank.

MODULE 2.0: RADIOLOGICAL AND CHEMICAL PROPERTIES OF URANIUM

TABLE OF CONTENTS

Introduction i
Before You Begin i
How to Complete this Module i
LEARNING OBJECTIVES 2-1
CHARACTERISTICS OF URANIUM 2-3
Radioactivity and Transformation Mechanisms 2-3
Serial Transformations 2-3
Naturally Occurring Radioactivity 2-5
Decay Products (Daughters) 2-9
Reclaimed or Recycled Uranium 2-9
Self-Check Questions 2-1 2-10
RADIOLOGICAL PROPERTIES 2-13
Radiological Properties of Uranium 2-13
Specific Activity 2-13
Effects of Enrichment on Specific Activity 2-16
Radiological Properties of Decay Products 2-18
Radiological Properties of Recycled Uranium 2-18
Neutron Hazard 2-19
Self-Check Questions 2-2 2-21
HUMAN RESPONSE INDICATORS OF URANIUM EXPOSURE 2-23
Self-Check Questions 2-3 2-24
COMPARATIVE HAZARDS AND RADIOLOGICAL VERSUS TOXIC LIMITS 2-25
Self-Check Questions 2-4 2-29
Activity 1: Word Association Game 2-31
Progress Review Meeting Form 2-36
MODULE SUMMARY 2-38

LIST OF TABLES

Table 2-1. Uranium Isotopic Percent (%) Abundances [Grams (g) of Isotope per 100 g of Natural Uranium] 2-6
Table 2-2. Radionuclides at Uranium Facilities 2-15
Table 2-3. Effects of Material Characteristics on Relative Hazards 2-26
Table 2-4. Unique Characteristics of Uranium Compounds at Fuel Cycle Facilities 2-28

LIST OF FIGURES

Figure 2-1. Secular Equilibrium....4
Figure 2-2. Transient Equilibrium....4
Figure 2-3. No Equilibrium....5
Figure 2-4. Actinium Series....7
Figure 2-5. Uranium Series....8
Figure 2-6. Specific Activity for Mixtures of U-238, U-234, and U-235....17
Figure 2-7. Percent of Total Alpha Activity by Isotope Versus Percent (%) Weight of U-235 Enrichment Calculated From S = (0.4 + 0.3E + 0.00034E2)10-6 Ci/g (Gaseous Diffusion Process)....18

MODULE 2.0: RADIOLOGICAL AND CHEMICAL PROPERTIES OF URANIUM

LEARNING OBJECTIVES

2.1 Upon completion of this module, you will be able to recognize the basic chemical, physical, and radiological properties of uranium and other radioactive materials present at fuel cycle facilities that are associated with the health physics program.

2.1.1 Recognize the properties of uranium as used in the fuel cycle.

2.1.2 Describe the effect of enrichment on the hazards.

2.1.3 Describe properties of decay products and recycled uranium.

2.1.4 Identify the human response indicators of uranium exposure.

2.1.5 Compare the chemical versus radiological hazards of uranium at various enrichments and solubilities.

This page intentionally left blank.

MODULE 2.0: RADIOLOGICAL AND CHEMICAL PROPERTIES OF URANIUM

Learning Objectives

When you finish this section, you will be able to:

2.1.1 Recognize the properties of uranium as used in the fuel cycle.

2.1.2 Describe the effect of enrichment on the hazards.

CHARACTERISTICS OF URANIUM

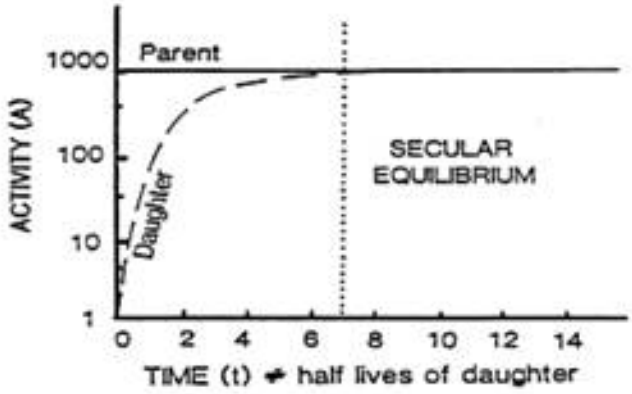
Radioactivity and Transformation Mechanisms

Radioactivity may be defined as spontaneous nuclear transformations (decays) that result in the formation of new elements. Different isotopes are transformed at different rates, and each isotope has its own characteristic transformation rate.

Serial Transformations

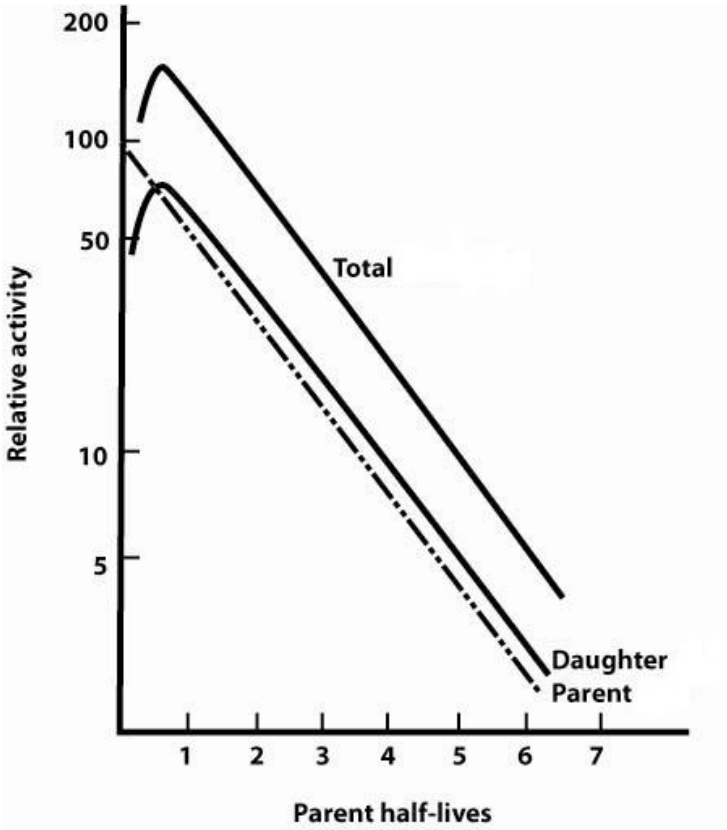
In radioactive decay, a parent isotope decays to a daughter isotope. A number of different isotopes undergo serial transformations (decays). When this happens in the case of a very long-lived parent and a short-lived daughter, an equilibrium condition called *secular equilibrium* develops after about 6 to 7 daughter half-lives. When secular equilibrium is reached, the activity of the daughter is equal to the activity of the parent. For example, if one curie of purified radium-226 is sealed in an air tight container, the activity of radon-222 in the container will increase until it also reaches one curie. The time to reach secular equilibrium is approximately seven half-lives of the decay product, so for our example, secular equilibrium would be reached after approximately 28 days. See Figure 2-1, Secular Equilibrium.

Figure 2-1. Secular Equilibrium



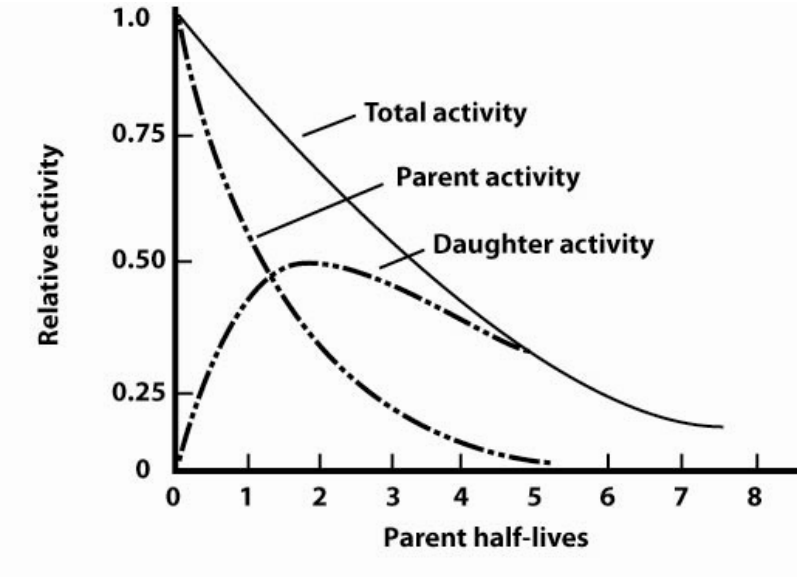
In those cases in which the half-life of the daughter is moderately less than that of the parent, a condition known as *transient equilibrium* develops (See Figure 2-2).

Figure 2-2. Transient Equilibrium



In transient equilibrium, the daughter activity exceeds that of the parent by an amount that is determined by the difference between their half-lives. An example of transient equilibrium is found in the beta decay of Ra-228 (5.76 year half-life) through Ac-228 (6.13 hour half-life) to Th-228 (1.91 year half-life). The Ac-228 achieves secular equilibrium with Ra-228, so their activities are equal; however, Th-228 comes into transient equilibrium with its parents, and has an activity equal to 1.5 times the activity of the Ra-228 or Ac-228. If the daughter is longer-lived than the parent, then no equilibrium condition can be attained. (See Figure 2-3)

Figure 2-3. No Equilibrium



Naturally Occurring Radioactivity

The naturally occurring radioactive substance that Bequerel discovered in 1896 was a mixture of several isotopes which were later found to be related to each other. They were members of long series of isotopes of various elements, all of which but the last were radioactive. (A radioactive series is a series of radioactive nuclides in which each member of the series is formed by the decay of the nuclide before it. The series ends with a stable nuclide.) Uranium, the most abundant of the radioactive elements in this mixture, consists of three different isotopes: U-234, U-235, and U-238. On a mass basis, the majority (99.2745%) of all atoms in natural uranium are U-238. Most of the remaining atoms (0.711%) are U-235, and a slight trace (0.0055%) are U-234.

The natural abundances of these isotopes are given in the second column of Table 2-1, Uranium Isotopic Percent (%) Abundances. Although all isotopes of uranium have similar chemical properties, each of the isotopes has significantly different nuclear properties. The isotope U-235 is usually the desired material for use in reactors.

Table 2-1. Uranium Isotopic Percent (%) Abundances [Grams (g) of Isotope per 100 g of Natural Uranium]

Isotope	Natural	Typical Commercial Feed Enrichment	Depleted
U-238	99.2745	97.01	99.75
U-235	0.711	2.96	0.25
U-234	0.0055	0.03	0.0005

The U-234 and U-238 belong to one family, the uranium series and the U-235 isotope is the first member of another series called the actinium series. See Figure 2-4, Actinium Series and Figure 2-5, Uranium Series. Both of these series are present in the nuclear fuel cycle. The most abundant of all naturally occurring radioisotopes, thorium-232, is the first member of still another long chain of successive radioisotopes. All of these radioactive series have several common characteristics. First is the fact that the first member of each series is very long-lived. A second characteristic common to all three naturally occurring series is that each has a gaseous member and, the radioactive gas in each case is a different isotope of the element radon. A third common characteristic is that the end product in each case is lead.

Figure 2-4. Actinium Series

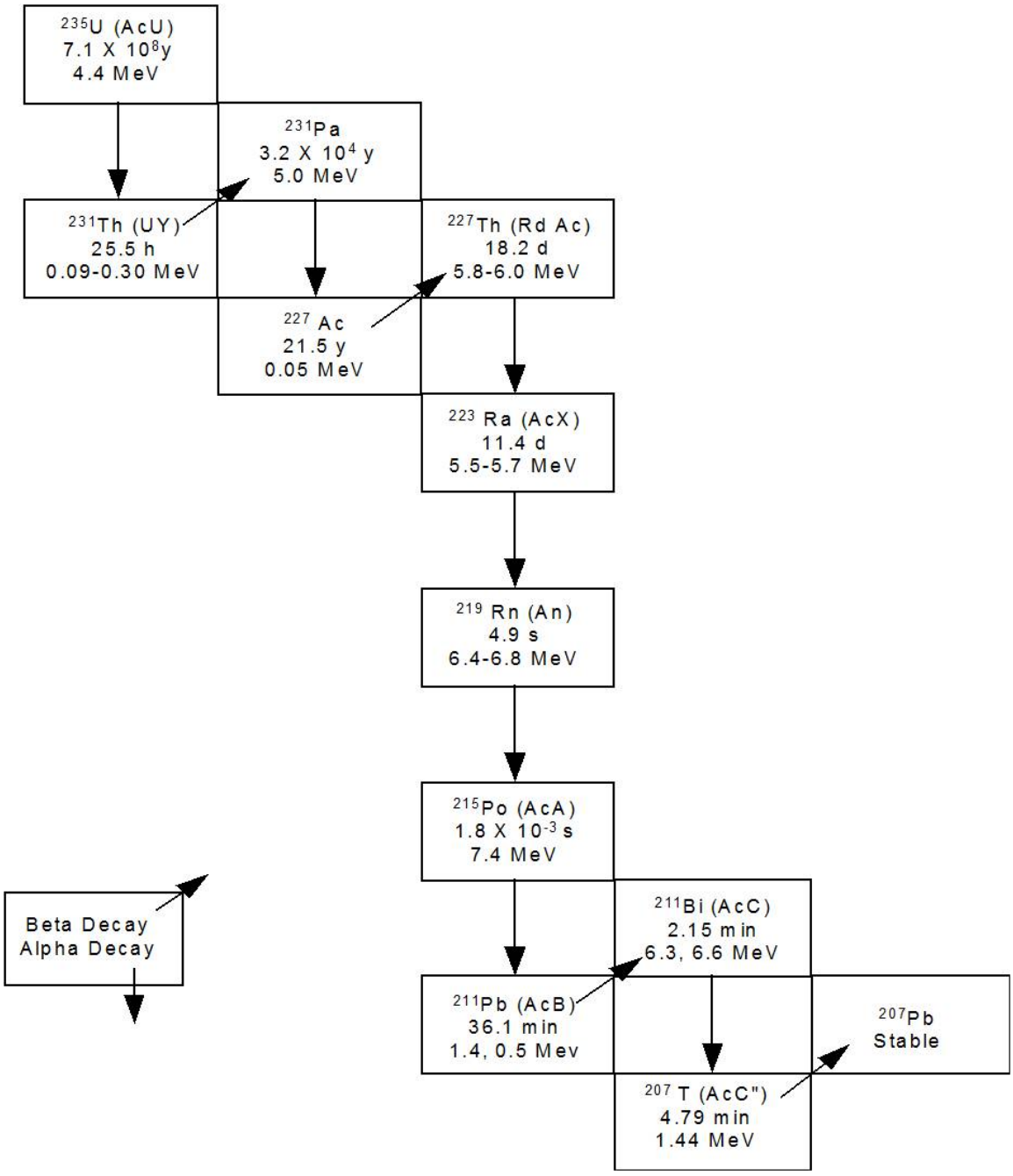
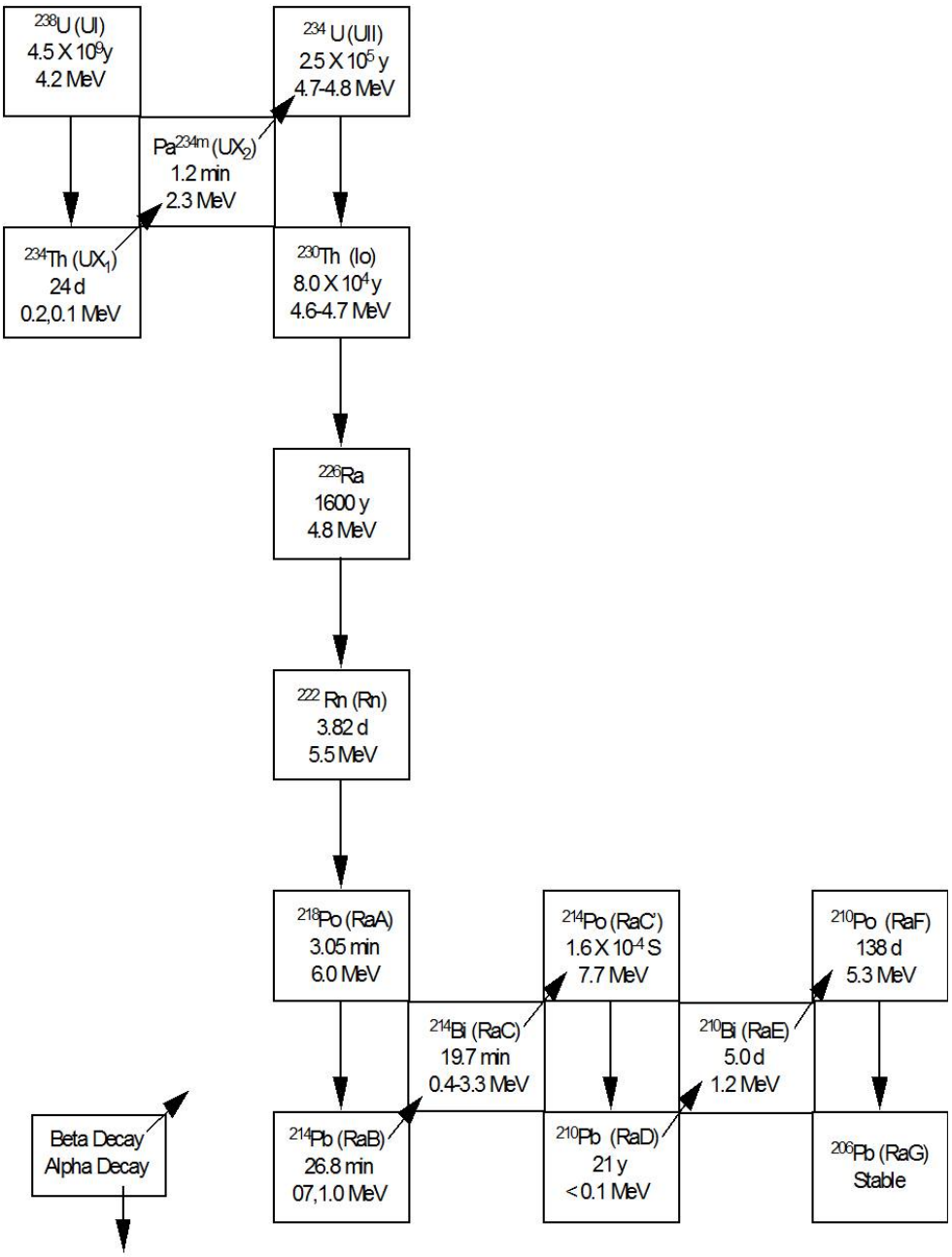


Figure 2-5. Uranium Series



Decay Products (Daughters)

As a result of weathering and the various chemical properties of the members of the decay chains, the decay products may not all be present in their maximum equilibrium amounts. These decay products can represent the most significant hazard from uranium ore in the mining and milling stages of the fuel cycle.

Typically, the most radiologically significant isotopes in natural uranium are isotopes of radium and its decay products (radon and polonium). Following the purification of the uranium from the ore, these decay products and most others will be removed. Therefore, in mining and recovery facilities, radium and its decay products would be expected to be a significant hazard, but would not be considered a hazard in other parts of the fuel cycle.

On the other hand, in newly purified uranium (U-234, U-235, and U-238), the immediate decay products of Th-234, Pa-234m, and Th-231 will have grown to their equilibrium levels within a few weeks. Because of the relatively short time for ingrowth of these products, they exist at all nuclear fuel cycle facilities and must be considered in the health physics program. In addition, trace amounts of the other decay products may exist, so it is prudent to conduct analysis for them in the effluent/environmental monitoring program when appropriate.

Reclaimed or Recycled Uranium

Some uranium feed material currently being handled has been reclaimed, or recycled, from reprocessed/spent reactor fuel. While recycling of commercial reactor fuel is not conducted in the United States, uranium has been recycled as part of the nuclear navy program, and recycling is an option in other countries.

The chemical processes by which recycled uranium is purified leave trace amounts of transuranic material (neptunium and plutonium) and fission products (Technetium-99 [Tc-99]). Recycled uranium also contains trace amounts of uranium isotopes not found in nature, such as U-236. Due to the low concentrations of these impurities and the fact that most uranium is not recycled, the radiological impact of these impurities is negligible in most cases. However, there are many routine chemical processes that tend to concentrate these impurities either in uranium products or in by-product materials. In these cases, appropriate radiological controls and effluent/environmental monitoring programs need to be instituted. The atomic vapor laser isotope separation (AVLIS) technique results in a higher specific activity in the tails due to a higher U-234 content.

Self-Check Questions 2-1

INSTRUCTIONS: Complete the following questions. Answers are located in the answer key section of the Trainee Guide.

Supply the missing letters or numbers in each statement.

1. The primary isotopes of uranium that exist in nature are U-234, U-_____, and U-238.

2. The majority of all atoms in natural uranium are U-_____.

3. Although all isotopes of uranium have similar chemical properties, each of the isotopes has significantly different _____ properties.

4. The isotope U-_____ is usually the desired material for use in reactors.

5. Radioactive equilibrium occurs when a fixed ratio between the activities of a decay product and its _____ exists.

6. If the half-life of the parent is much longer than that of the decay product, a special form of equilibrium called _____ equilibrium is possible.

7. The time to reach secular equilibrium is approximately _____ half-lives of the decay product.

8. A radioactive series is a series of radioactive nuclei in which each member of the series is formed by the _____ of the nuclide before it. The series ends with a _____ nuclide.

9. Typically, the most radiologically significant isotopes in natural uranium are isotopes of _____ and its decay products (radon and polonium).

10. Following the _____ of the uranium from the ore, these decay products (radon and polonium) and most others will be _____.

11. In newly purified uranium (U-234, U-235, and U-238), the immediate decay products of Th-234, Pa-234m, and Th-231 will have grown to their _____ levels within a few weeks. Because of the relatively short time period for ingrowth of these products, they exist at all nuclear _____ _____ facilities and must be considered in the _____ physics program.

12. Some uranium feed material currently being handled has been reclaimed, or _____, from reprocessed/spent reactor fuel.

13. The chemical processes by which recycled uranium is purified leave _____ amounts of _____ material and fission products.

14. Appropriate radiological _____ and effluent/environmental _____ programs need to be instituted when routine chemical processes tend to concentrate _____ either in uranium products or in by-product materials.

15. The atomic vapor laser isotope separation (AVLIS) technique results in higher specific activity in _____ than is currently found.

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

This page intentionally left blank.

Learning Objectives

When you finish this section, you will be able to:

2.1.1 Recognize the properties of uranium as used in the fuel cycle.

2.1.2 Describe the effect of enrichment on the hazards.

2.1.3 Describe properties of decay products and recycled uranium.

RADIOLOGICAL PROPERTIES

Radiological Properties of Uranium

The primary isotopes of uranium are all long-lived alpha emitters with energies in the range of 4 to 5 MeV. See Table 2-2, Radionuclides at Uranium Facilities. For this reason, uranium is usually considered to be largely an internal hazard, with the primary concern being inhalation under normal operating conditions. However, because many of the radionuclides in the decay chains are beta emitters, uranium can also be a hazard for skin exposure if there is direct contact.

Since specific activity is a factor in internal dosimetry, and the specific activity of uranium increases with enrichment, enriched uranium represents a greater radiological hazard.

Specific Activity

Specific activity is the quantity of radioactivity per unit mass of that isotope. It is an important factor in assessing the radiological hazards at fuel cycle facilities. Specific activity provides an indication of the concentration of radioactivity, or the relationship between the mass of radioactive material and the activity.

The following formula shows how to calculate specific activity.

Formula for Specific Activity (SA)

$$SA = \frac{3.578 \times 10^{5}}{T_{1/2}\ (\text{atomic mass})} \quad (\text{Ci/gm})$$

(where $T_{1/2}$ is the half-life in years)

For example, calculate the specific activity of U-238:

$$SA = \frac{3.5781 \times 10^{5}}{(4.47 \times 10^{9})\,(238)} = 3.4 \times 10^{-7}\ \text{Ci/gm}$$

It would take almost 3 million grams of U-238 to have a curie of activity.

Table 2-2. Radionuclides at Uranium Facilities

		Energies (MeV) and Abundances of Major Radiations		
Nuclide	**Half-Life**	**Alpha**	**Beta**	**Gamma**
Primary Uranium Isotopes				
Uranium-238 (U-238)	4.51 x 10^9y	4.15 (25%) 4.20 (75%)	--	--
Uranium-235 (U-235)	7.1 x 10^8y	4.37 (18%) 4.40 (57%) 4.58 (8%)	--	0.144 (11%) 0.185 (54%) 0.204 (5%)
Uranium-234 (U-234)	2.47 x 10^5y	4.72 (28%) 4.77 (72%)	--	0.053 (.2%)
Decay Products				
Thorium-234 (Th-234)	24.1d	--	0.103 (21%) 0.193 (79%)	0.063 (3.5%) 0.093 (4%)
Protactinium-234m (Pa-234m)	1.17m	--	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
Thorium-231 (Th-231)	25.5h		0.140 (45%) 0.220 (15%) 0.350 (40%)	0.026 (2%) 0.084 (10%)
Impurities				
Technetium-99 (Tc-99)	2.12 x 10^5y	--	0.292	--
Neptunium-237 (Np-237)	2.14 x 10^6y	4.78 (75%) 4.65 (12%)		0.030 (14%) 0.086 (14%) 0.145 (1%)
Plutonium-238 (Pu-238)	86.4y	5.50 (72%) 5.46 (28%)		
Plutonium-239 (Pu-239)	24,390y	5.16 (88%) 5.11 (11%)		0.052 (0.02%)
Plutonium-240 (Pu-240)	6,580y	5.17 (76%) 5.12 (24%)		
Plutonium-241 (Pu-241)	13.2y		0.021	
Uranium-236 (U-236)	2.39 x 10^7y	4.47 (24%) 4.52 (76%)		

y = years m = months
d = days h = hours

Effects of Enrichment on Specific Activity

Abundances of uranium isotopes for typical commercial feed enrichment were previously given in Table 2-1, Uranium Isotopic Percent (%) Abundances. Note from this table that as the uranium is enriched in U-235, the relative amount of U-234 is increasing at an even greater rate. For example, in going from natural uranium to commercial feed enrichment in Table 2-1, the abundance of U-235 has increased by a factor of approximately 4.2 (2.96/0.711), while the percentage of U-234 has increased by a factor of 5.4 (0.03/0.0055). This is significant due to the relatively short half-life of U-234 when compared to the other uranium isotopes present. The specific activity of uranium increases as the enrichment increases for the current enrichment technologies (gaseous diffusion and centrifuge). See Figure 2-6, Specific Activity for Mixtures of U-238, U-234, and U-235; and Figure 2-7, Percent of Total Radioactivity by Isotope Versus Percent (%) Weight of U-235 Enrichment. As enrichment increases, the radiological hazard from intake of uranium increases.

Because of the increased specific activity with enrichment, it is important for health physics personnel to be able to calculate specific activity at various enrichments. The alpha specific activity of uranium enriched by gaseous diffusion or the centrifuge process can be estimated for U-238, U-235, and U-234 by using the following equations:

$$SA = 3.6E\text{-}7 \text{ curies/gram U} \quad \text{Depleted U}$$

$$SA = [0.4 + 0.38 (\text{enrichment}) + 0.0034 (\text{enrichment})^2] \times 10^{-6} \quad [\text{enrichment} \geq 0.72]$$

(where enrichment is the percentage by weight of U-235, expressed as percent)

Note that the second equation will not be completely accurate if the uranium has been blended from other enrichments or from recycled uranium.

The only other radiations emitted directly from the uranium isotopes are relatively low-energy gamma rays, primarily from U-235. At low enrichments and due to the significant self-absorption of low-energy gamma radiation by uranium, this gamma radiation is typically not the limiting factor in radiological control.

Figure 2-6. Specific Activity for Mixtures of U-238, U-234, and U-235 (Ci of radioactivity per gram uranium)

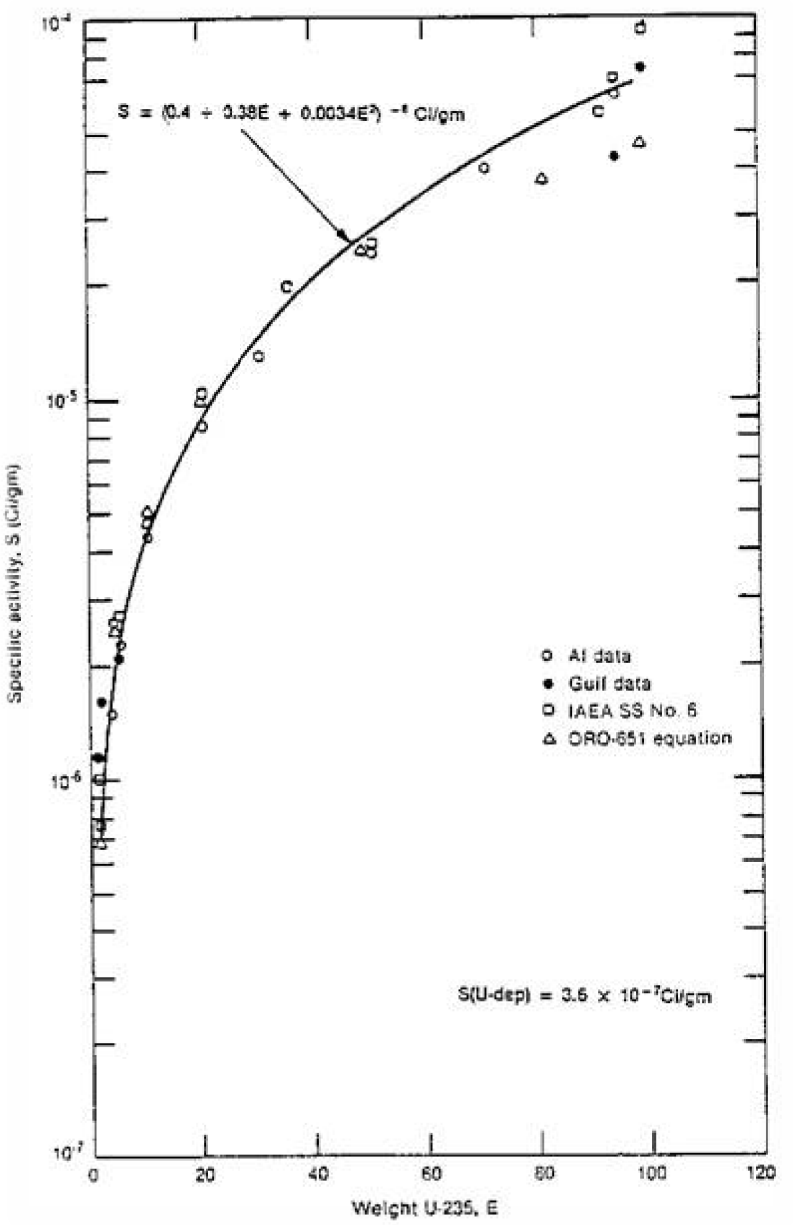
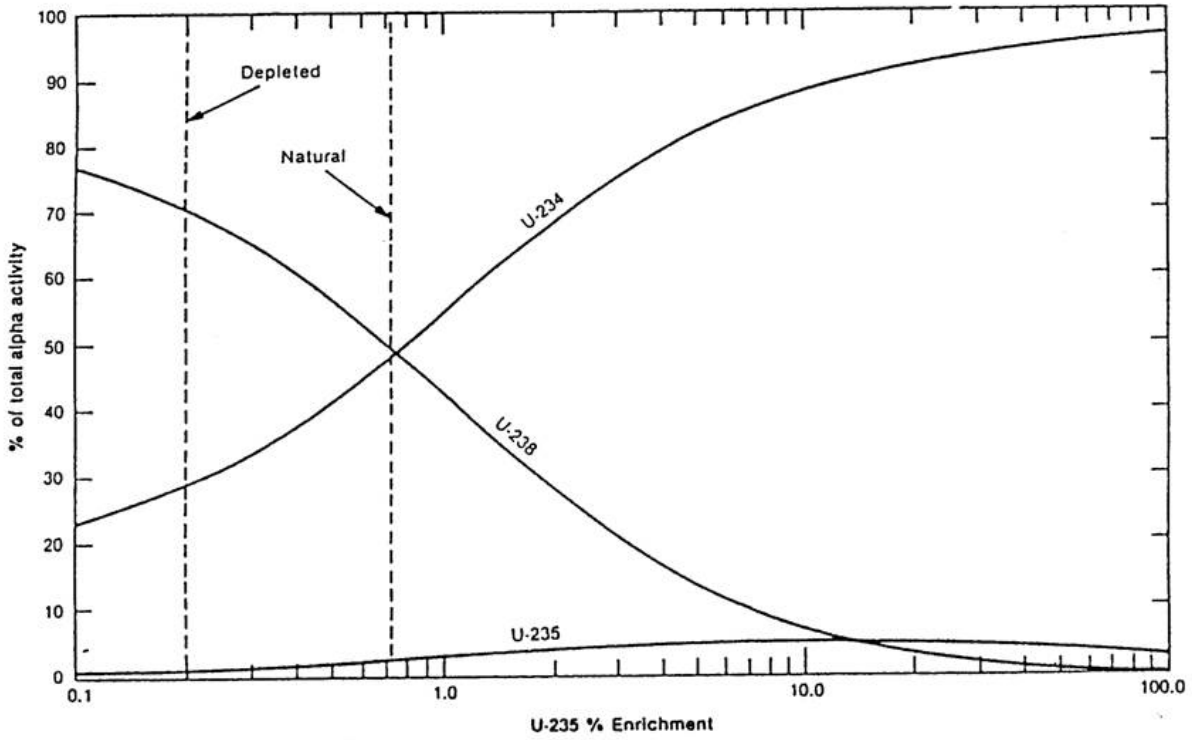


Figure 2-7. Percent of Total Alpha Activity by Isotope Versus Percent (%) Weight of U-235 Enrichment Calculated From S = (0.4 + 0.3E + 0.00034E2)10-6 Ci/g (Gaseous Diffusion Process).



Radiological Properties of Decay Products

The immediate decay products of the uranium isotopes are primarily beta emitters. See Table 2-2, Radionuclides at Uranium Facilities. The internal hazard of beta emitters is usually overshadowed by the alpha-emitting uranium isotopes. However, they are frequently responsible for the most significant hazards from external radiation, primarily due to the high-energy beta emitted (2.29 MeV) from Pa-234m.

As with most beta emitters, the external hazard is principally to the skin and lens of the eye of exposed individuals. In addition to the decay products listed in Table 2-2, other decay products from the decay chains will also be present in mining and recovery operations and will contribute significantly to radiation doses at these facilities.

Radiological Properties of Recycled Uranium

The isotopes of primary concern from recycled uranium are:

- Tc-99
- U-232
- Transuranics (Np-237, Pu-238, and Pu-239)

Tc-99 is a fission product with a relatively low-energy beta emission and a very long half-life (see Table 2-2, Radionuclides at Uranium Facilities). This form of Tc-99 should not be confused with the metastable form (Tc-99m), which is a gamma emitter with a very short half-life (6.0 h) and is widely used in the medical community. The low-energy beta (0.292 MeV) from Tc-99 is easily missed at facilities if the surveys are primarily designed to detect the more common high-energy betas associated with Pa-234m. Typically, levels of Tc-99 have not been the controlling factor at facilities. However technetium is more volatile than uranium and can become airborne more easily. In facilities involving uranium melting, casting, or uranium chip burning, residues in ventilation systems have been observed to have higher Tc-to-U ratios than in the materials being handled. This can lead to areas of Tc-99 contamination in unexpected locations and environmental emissions of Tc-99 even when the uranium is adequately confined.

The uranium isotopes that will increase as a result of the use of recycled uranium are U-232, U-234, and U-236. However, the only one of these isotopes that will cause any significant health physics concern is U-232. This hazard is primarily due to the penetrating gamma activity of its decay products, which largely arise from the immediate decay product, Th-228. For example, if recycled uranium is widely used, estimates have been made that the level of gamma activity in gaseous diffusion enrichment equipment would increase by a factor of 3 due to the gamma radiation associated with the U-232 that would be present.

Transuranics (neptunium and plutonium isotopes) are typically found in small quantities in recycled uranium and the radiological controls in place for uranium hazards will normally be adequate to control them. However, they do have higher specific activities and lower limits for intake, so facilities that have reason to suspect the presence of transuranics should verify the amounts present and ensure appropriate controls. This may be particularly applicable when the source of uranium is uncertain, such as material that may have been produced in the former Soviet Union.

Neutron Hazard

Uranium fluorides and some other compounds of uranium at fuel cycle facilities will produce a small amount of neutron radiation as the result of the (alpha-n) reaction. This reaction involves the emission of neutron radiation that results from alpha interaction with certain low atomic number materials such as fluorine. The neutron dose rate will increase with these compounds with the increase in enrichment of the uranium. For example, UF_6 cylinders containing 5% enriched uranium will have a contact neutron dose rate of approximately 0.2 mrem/hr, while a cylinder containing natural uranium would have a neutron dose rate of about 0.01 mrem/hr. These low dose rates are a concern for workers who are spending several hours a week in areas containing large quantities of UF_6, such as UF_6 storage areas.

It is important to measure for both gamma and neutron dose rates. Note that gamma doses received by workers near UF_6 cylinders are not a good indicator of neutron doses since higher gamma dose rates are associated with empty cylinders (due to remaining residues), while higher neutron doses are associated with full cylinders. (Residues produce a high gamma hazard, while full cylinders are a neutron dose hazard.)

Self-Check Questions 2-2

INSTRUCTIONS: Answer the following questions. Answers are located in the answer key section of the Trainee Guide

Use Table 2-2, Radionuclides at Uranium Facilities to complete the following two statements.

1. The primary isotopes of uranium are all long-lived _____ emitters with energies in the range of 4 to 5 MeV. For this reason, uranium is usually considered to be largely an internal hazard, with the primary concern being inhalation under normal operating conditions. The only other radiations emitted directly from the uranium isotopes are relatively low-energy _____ primarily from U-235.

2. Because many of the radionuclides in the decay chains are _____beta emitters, uranium can also be a hazard for skin exposure if there is direct contact.

Complete the following questions.

3. What is specific activity and why is it important?

4. When enrichment increases in gaseous diffusion and centrifuge enrichment technologies, what happens to specific activity of uranium?

5. As enrichment increases the radiological hazard from intake of uranium does what?

6. As with most beta emitters, the external hazard is principally to what two body areas of an exposed individual?

7. What are the isotopes of primary concern from recycled uranium?

8. List two differences between technetium and uranium.

9. In facilities involving uranium melting, casting, or uranium chip burning, residues in ventilation systems have been observed to have higher Tc-to-U ratios than in the materials being handled. What could this lead to?

10. What uranium isotopes will increase as a result of the use of recycled uranium?

11. Which one of the isotopes in response to question #10 above causes any significant health physics concern and why?

12. If facilities suspect the presence of transuranics, what should they do and why?

13. Uranium fluorides and some other compounds of uranium at fuel cycle facilities will produce a small amount of neutron radiation as the result of the (alpha-n) reaction. What does this involve?

14. Why is it a good idea to measure for both gamma and neutron dose rates near UF_6 cylinders?

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

Learning Objective

When you finish this section, you will be able to:

2.1.4 Identify the human response indicators of uranium exposure.

HUMAN RESPONSE INDICATORS OF URANIUM EXPOSURE

Uranium has been recognized as a chemical hazard since the early 1800s. Through the administration of uranium nitrate for the treatment of diabetes (an accepted practice in the late 1800s), it was determined that the intake of excessive amounts of soluble uranium resulted in inhibited reabsorption of vital fluids in the tubules of the kidneys. This resulted in changes in the composition of the urine. Those changes include the following:

- Proteinuria (excess serum protein)
- Glucosuria (the presence of glucose)
- Polyuria (excess volume)
- Albuminuria (the presence of serum albumin)

The most sensitive biological indicators of kidney damage are glucosuria and polyuria. However, these values are only useful if the normal levels in affected individuals have been previously determined. Lacking that information, albuminuria is the best biological indicator of an excess intake of soluble uranium.

Because of its chemical toxicity, the NRC has regulations limiting the intake of soluble uranium to 10 milligrams in a week [10 CFR Part 20.1201(e)] and for enrichments not greater than 5%, an average air concentration of 0.2 milligrams of uranium per cubic meter for a 40-hour workweek (10 CFR Part 20 Appendix B, footnote 3).

Self-Check Questions 2-3

INSTRUCTIONS: Answer the following questions. Answers are located in the answer key section of the Trainee Guide

Circle the best multiple choice response.

1. If normal levels in affected individuals have not been previously determined, what is the best biological indicator of an excess intake of soluble uranium?

   A. Proteinuria
   B. Glucosuria
   C. Polyuria
   D. Albuminuria

2. The NRC limits the intake of soluble uranium to _____ milligrams in a week.

   A. 10
   B. 25
   C. 35
   D. 50

3. The NRC limits the intake of soluble uranium to an average air concentration of _____ milligrams of uranium per cubic meter for a 40-hour workweek for enrichments not greater than 5%.

   A. 1.0
   B. 0.7
   C. 0.5
   D. 0.2

You have completed this section.
Please check off your progress on the tracking form.
Go to the next section.

Learning Objective

When you finish this section, you will be able to:

2.1.5 Compare the chemical versus radiological hazards of uranium at various enrichments and solubilities.

COMPARATIVE HAZARDS AND RADIOLOGICAL VERSUS TOXIC LIMITS

Table 2-3, Effects of Material Characteristics on Relative Hazards, presents a summary of the chemical and radiological hazards of uranium.

Table 2-4, Unique Characteristics of Uranium Compounds at Fuel Cycle Facilities, provides an indication of the forms of uranium and hazards present at fuel cycle facilities.

Table 2-3. Effects of Material Characteristics on Relative Hazards

Characteristics	Material	Relative External Hazard	Relative Internal Hazard
I. Enrichment	A. Depleted, natural, and slightly enriched uranium	1. Little penetrating radiation. 2. Moderate nonpenetrating radiation from bare uranium.	1. Inhalation results in potential chemical toxicity and/or radiation doses to bone surfaces, lungs, and effective dose equivalents.
	B. Moderately to highly enriched uranium	1. Significance of penetrating radiation increases with enrichment. 2. Nonpenetrating radiation from bare uranium remains moderate.	1. Same as above, except that higher enrichment means higher doses per unit mass inhaled. For chronic exposures, radiation doses become more significant and chemical toxicity less significant as enrichment increases.
II. Chemical Form	A. Transportability * Class D (Soluble)	1. Chemical form does not significantly affect external hazard except that neutron radiation levels increase in homogeneous fluoride compounds.	1. For acute exposure to any enrichment, chemical toxicity is more limiting than radiological Annual Limits on Intake. 2. For chronic exposures, chemical toxicity is more limiting up to 15% enrichment; above that level, the nonstochastic dose limit for bone surfaces becomes limiting.

Table 2-3. Effects of Material Characteristics on Relative Hazards

Characteristics	Material	Relative External Hazard	Relative Internal Hazard
II. Chemical Form (cont.)	B. Transportability *Class W	1. Chemical form does not significantly affect external hazard except for fluoride compounds/mixtures.	1. For acute exposures, chemical toxicity is more limiting up to 39% enrichment; above that level, the effective dose equivalent becomes limiting. 2. For chronic exposures, chemical toxicity is more limiting up to 1.3% enrichment; above that level, the effective dose equivalent becomes limiting.
	C. Transportability *Class Y (Insoluble)	1. Chemical form does not significantly affect external hazard except for fluoride compounds/ mixtures.	1. Chronic and acute inhalation are limited by effective dose equivalent resulting primarily from lung dose.
III. Physical Form	A. Nondispersible	1. Nonpenetrating dose rates are slightly higher from metal than from compounds. 2. Penetrating dose rates are not significantly affected by physical form.	1. Nondispersible forms generally don't pose an internal hazard.
	B. Dispersible	1. Nonpenetrating dose rates are slightly higher from metal than from compounds. 2. Penetrating dose rates are not significantly affected by physical form.	1. Dispersible forms pose internal hazards as described under "I. Enrichment" and "II. Chemical Form."

* Transportability classes discussed in Module 4.

Table 2-4. Unique Characteristics of Uranium Compounds at Fuel Cycle Facilities

Uranium Compound	Solubility	Inhalation Class	Unique Characteristics and Other Comments
U_3O_8 Triuranium Octoxide (Yellowcake)	Moderate	Class W or Class Y	◙ Ore dust and radon emission from ore crushing and storage ◙ Windblown particulates and radon emission from the tailings and disposal area
UO_2 Uranium Dioxide (Brown Oxide, or Uraninite)	Low	Class Y	◙ Widely used to form pellets ◙ Finely powdered form ignites spontaneously ◙ Potential for airborne contamination ◙ Low potential for internal exposure
UO_3 Uranium Trioxide (Orange Oxides)	Moderate	Class W	◙ Uranium decay products tend to concentrate in unreacted waste ◙ Decomposes when heated
$UO_4(OH)_2$ Uranium Peroxide	Moderate	Class W	◙ Slightly soluble in water and dissolves in HCl
UF_4 Uranium Tetrafluoride (Green Salt)	Moderate	Class W	◙ Highly corrosive
UF_6 Uranium Hexafluoride	High	Class D	◙ Highly corrosive and hazardous as a gas ◙ Reacts vigorously with water, alcohol, ether, and most metals ◙ Gas at relatively low temperatures
UO_2F_2 Uranyl Fluoride	High	Class D	◙ Hazardous in liquid and gaseous forms

Self-Check Questions 2-4

INSTRUCTIONS: Answer the following questions. Answers are located in the answer key section of the Trainee Guide.

Answer True or False to the following statements.

1._____ With depleted, natural, and slightly enriched uranium the relative internal hazard occurs due to inhalation which results in potential chemical toxicity and/or radiation doses to bone surfaces, lungs, and effective dose equivalents.

2._____ In moderately to highly enriched uranium, the relative external hazard of penetrating radiation decreases with enrichment.

3._____ For chronic exposures from moderately to highly enriched uranium, radiation doses become more significant and chemical toxicity less significant as enrichment increases.

4._____ In transportability class D material, the chemical form does not significantly affect external hazard except that neutron radiation levels increase in homogeneous fluoride compounds.

5._____ For acute exposure to any enrichment of transportability class D material, chemical toxicity is more limiting than radiological Annual Limit on Intake.

6._____ For chronic exposures from transportability class D material, chemical toxicity is more limiting up to 15% enrichment.

7._____ In transportability class W material, chemical form does not significantly affect external hazard.

8._____ For acute exposure to transportability class W material, chemical toxicity is less limiting up to 39% enrichment.

9._____ For chronic exposures to transportability class W material, chemical toxicity is more limiting up to 5% enrichment.

10._____ In transportability class Y material, chemical form does not significantly affect external hazard except for fluoride compounds/mixtures.

11._____ In transportability class Y material, chronic and acute inhalation are limited by effective dose equivalent resulting primarily from lung dose.

12._____ Nondispersible forms of material generally do pose an internal hazard.

13._____ Dispersible forms of material generally do pose an internal hazard.

14._____ In nondispersible material, nonpenetrating dose rates are slightly higher from compounds than from metals.

15. Match the uranium compounds listed in column A with the characteristics listed in column B. (Hint: Some responses may be used more than once.)

Column A **Uranium Compounds**	**Column B** **Characteristics**
A. U_3O_8	1._____ Highly corrosive
B. UO_2	2._____ Belongs to inhalation class W or class Y
C. UO_3	3._____ Slightly soluble in water and dissolves in HCl
D. $UO_4 \cdot nH_2O$	4._____ Finely powdered form ignites spontaneously
E. UF_4	5._____ Hazardous in liquid and gaseous forms
F. UF_6	6._____ Decomposes when heated
G. UO_2F_2	7._____ High solubility

Activity 1: Word Association Game

PURPOSE: The purpose of this activity is to recognize basic chemical, physical, and radiological properties of uranium and other radioactive materials present at fuel cycle facilities that are associated with the health physics program.

INSTRUCTIONS: Complete the following activity by first reviewing the words given and then developing an association [in the form of a question] as it relates to the words. The first one is done as an example for you.

Example:

U_3O_8
UO_2
UO_3
$UO_4 \cdot nH_2O$
UF_4
UF_6

Association
What are uranium compounds found at fuel cycle facilities?

1. U-234
   U-235
   U-238

   Association

2. Occurs when a fixed ratio between the activities of a decay product and its parent exists

   Results in a decay product activity that decreases with the half-life characteristic of the parent as long as the parent is present

   Association

3. Th-232
   U-235
   U-238
   Ends with a stable nuclide

   Association

4. Can represent the most significant hazard from uranium ore
   After purification of uranium from ore, usually removed
   Radon and polonium
   Th-234, Pa-234m, and Th-231
   Primarily beta emitters — Association

5. Not conducted commercially in the United States
   Has been part of the nuclear navy program
   Option in other countries — Association

   Chemical processes for purification may leave trace amounts of transuranic material and fission products

   Could contain trace amounts of uranium isotopes not found in nature, such as U-236 — Association

6. Long-lived alpha emitters with energies in the range of 4 to 5 MeV
   Beta emitters
   Internal hazard
   External hazard
   Hazard for skin exposure if there is direct contact
   Specific activity increases with enrichment — Association

7. Amount of radioactivity per mass
   Important factor in assessing radiological hazards
   Provides an indication of the concentration of radioactivity — Association

8.	technetium-99 neptunium-237 plutonium-238 plutonium-239 plutonium-240 plutonium-241 uranium-236	Association
9.	Typically found in small quantities in recycled uranium Radiological controls in place for uranium hazards normally are adequate to control them Do have higher specific activities and lower limits for intake Facilities should verify the amounts present and ensure appropriate controls	Association
10.	Will produce a small amount of neutron radiation as the result of the alpha-n reaction Neutron dose rate will increase with these compounds with the increase in enrichment of uranium	Association

11. Intake of excessive amounts of soluble uranium resulted in inhibited reabsorption of vital fluids in the tubules of the kidneys — Association

    Changes in the composition of urine
    Proteinuria
    Glucosuria
    Polyuria
    Albuminuria

    Intake of soluble uranium limited to 10 milligrams in a week. Limits for enrichments not greater than 5%, an average air concentration of 0.2 milligrams of uranium per cubic meter for a 40-hour work week

12. For acute exposure to any enrichment of transportability class D material, this is more limiting than radiological Annual Limits on Intake — Association

    For chronic exposures of transportability class D material, this is more limiting up to 15% enrichment

    For acute exposures to transportability class W material, this is more limiting up to 39% enrichment

    For chronic exposures to transportability class W material, this is more limiting up to 1.3% enrichment

13. Nondispersible
    Dispersible — Association

It's time to schedule a progress meeting with your administrator. Review the progress meeting form on the next page. In Part III, as a Regulator, write your specific questions to discuss with the administrator.

PROGRESS REVIEW MEETING FORM

Date Scheduled: _____Location:_____

I. The following suggested items should be discussed with the administrator as to how they pertain to your current position:

- Naturally occurring isotopes of uranium and abundances
- Radioactive equilibrium
- Reclaimed or recycled uranium
- Radiological properties of uranium
- Specific activity
- Effects of enrichment on specific activity
- Neutron hazard
- Human response indicators of uranium exposure
- Comparative hazards and radiological versus toxic limits
- Uranium compounds at fuel cycle facilities

II. Use the space below to take notes during your meeting.

III. As a Regulator:

- Tell me more about the properties of uranium in the fuel cycle facilities that I will be involved with in my work.
- Please explain to me the decay products that I will come into contact with in my work at the various fuel cycle facilities.
- Where can I obtain effluent/environmental monitoring program reports that discuss health physics concerns mentioned in this module?
- I would like for you to show me an example of how specific activity was calculated for various enrichments at a particular fuel cycle facility.

Use the space below to write your specific questions.

IV. Further assignments? If yes, please note and complete. If no, initial completion of progress meeting on tracking form.

Ensure that you and your administrator have dated and initialed your progress on your tracking form for this module.
Go to the module summary.

MODULE SUMMARY

Recognizing physical, chemical, and radiological properties of uranium and other associated radionuclides as they apply in the nuclear fuel cycle are important because they impact the decisions made by health physics staff in protecting the health of the employees and the environment.

Congratulations! You are ready to go to the next assigned module.