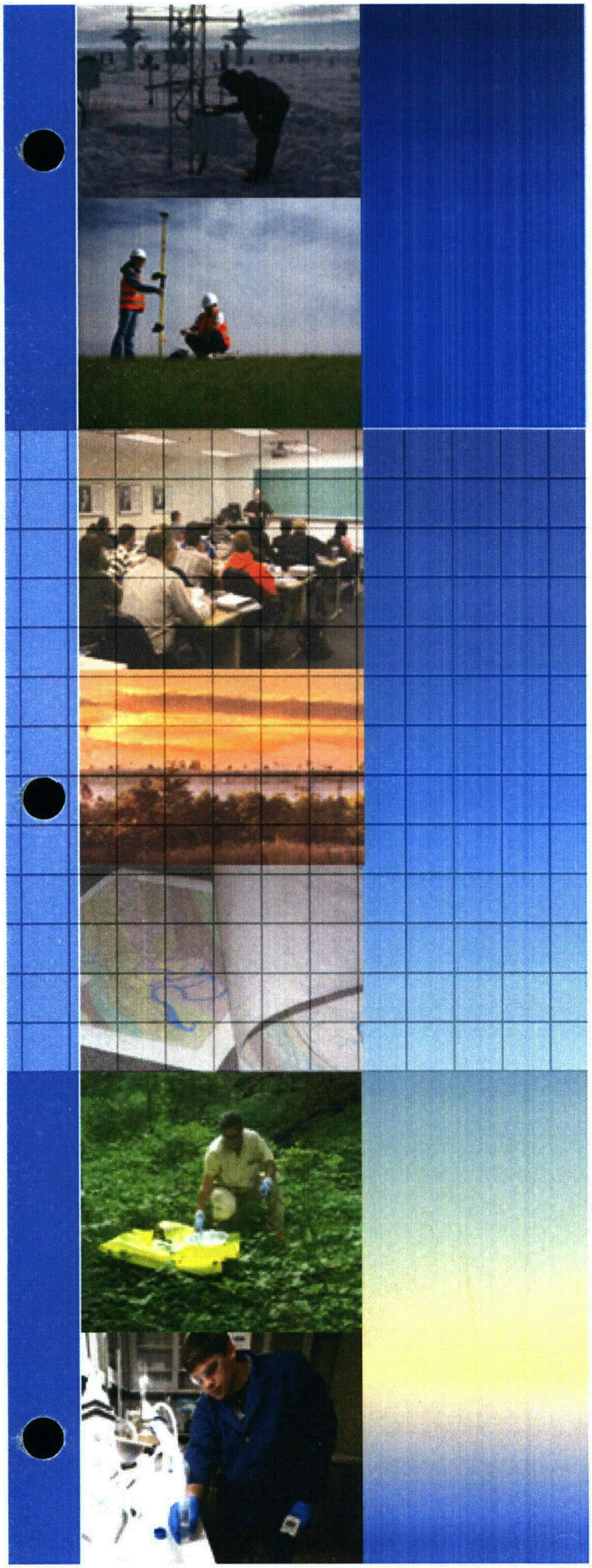

TECHNICAL BASIS DOCUMENT TO SUPPORT THE REVISION OF REGULATORY GUIDE 4.14, REVISION 1, "RADIOLOGICAL EFFLUENT AND ENVIRONMENTAL MONITORING AT URANIUM MILLS" (Final Report)

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Prepared for the

U.S. Nuclear Regulatory Commission

Office of Federal and State Materials and Environmental Management Programs

Division of Waste Management and Environmental Protection

Uranium Recovery Licensing Branch

FEBRUARY 2014

ORAU

OAK RIDGE ASSOCIATED UNIVERSITIES

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Office of Federal and State Materials and Environmental Management Programs
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FINAL REPORT

FEBRUARY 2014

Prepared by Oak Ridge Associated Universities under the Oak Ridge Institute for Science and Education contract, number DE-AC05-06OR23100, with the U.S. Department of Energy under interagency agreement (NRC FIN No. F1008) between the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy.

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ACKNOWLEDGEMENTS

The Oak Ridge Associated Universities (ORAU) appreciated the opportunity to provide technical support to the U.S. Nuclear Regulatory Commission (NRC). The authors gratefully acknowledge the following individuals and organizations for their contributions and assistance with this project:

TECHNICAL SUPPORT

James Webb of NRC (NRC Technical Project Manager)

Stephen Giebel of NRC

Elise Striz, Ph.D., of NRC

Duane Schmidt, CHP, of NRC

Jason Davis of ORAU

Ashley Golden, Ph.D., of ORAU

Roger Halsey, CHP, of ORAU

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ACRONYMS

ADU	ammonium diuranate
ALARA	as low as reasonably achievable
ALI	annual limit on intake
ANSI	American National Standards Institute
CFR	Code of Federal Regulations
CPP	Central Processing Plant
CSM	conceptual site model
DQA	Data Quality Assessment
DQO	Data Quality Objectives
EPA	U.S. Environmental Protection Agency
FGR	Federal Guidance Report
GPS	global positioning systems
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ICRP	International Commission on Radiological Protection
ISR	in situ recovery
LLD	lower limit of detection
MDC	minimum detectable concentration
mrem/yr	millirems per year
MQO	measurement quality objectives
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
PIC	pressurized ionization chamber
QA	Quality Assurance
RG	Regulatory Guide
TBD	Technical Basis Document
TEDE	total effective dose equivalent
UMTRCA	Uranium Mill Tailings Radiation Control Act
USC	United States Code

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TECHNICAL BASIS DOCUMENT TO SUPPORT THE REVISION OF REGULATORY GUIDE 4.14, REVISION 1, "RADIOLOGICAL EFFLUENT AND ENVIRONMENTAL MONITORING AT URANIUM MILLS"

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) requested that Oak Ridge Associated Universities (ORAU), via the Oak Ridge Institute for Science and Education (ORISE) contract, develop a technical basis document (TBD) supporting the revision of Regulatory Guide 4.14 (RG 4.14), Revision 1, *Radiological Effluent and Environmental Monitoring at Uranium Mills*, issued in April 1980. The existing RG 4.14 is limited to conventional mills. The basis for inclusion of in situ recovery (ISR) and heap leach facilities, respectively, is included in this report, as well as recommendations for the preoperational and operational environmental and effluent monitoring programs at these three types of uranium recovery facilities. In addition, the current monitoring programs described in RG 4.14 have been expanded to include non-radiological contaminants for groundwater and surface water for each recovery method. The addition of a land use census is described, and an integrated, risk-informed, decision-making process is introduced.

The current regulatory guidance in RG 4.14 also requires updating to incorporate current provisions of Title 10 of the Code of Federal Regulations Part 20, *Standards for Protection Against Radiation* (10 CFR 20), and other applicable NRC regulations and guidance. The revised RG 4.14 will support the acquisition of defensible environmental and effluent data for licensees at existing and new uranium recovery facilities.

This TBD is divided into several chapters: Chapter 1 provides an introduction to the TBD including the scope and objectives of this project. Chapter 2 describes the conventional (mill), ISR, and heap leach uranium recovery methods, followed by the technical basis in Chapter 3. Chapter 3 examines in detail the regulatory position of the current regulatory guide; based on that examination, recommendations and applicability to one or more of the three uranium recovery facilities are provided along with a technical basis justification for each recommendation. Advances in technology since RG 4.14 was first issued are also incorporated into Chapter 3. These include computer codes, global positioning systems, solar powered air samplers, and use of all-terrain vehicles for gamma ray monitoring. Approximately 100 recommendations are offered in this document for NRC consideration in the revision of RG 4.14. These recommendations (either to change the existing guidance or to maintain the current approach, i.e., a "no change" recommendation) are included in this TBD and summarized in Appendix A. Appendices B and C provide summary tables of the updated preoperational and operational monitoring programs, respectively. Appendix D addresses data reporting considerations. Appendix E introduces the issue of risk-informed decision making.

1. INTRODUCTION

1.1. HISTORICAL AND REGULATORY FRAMEWORK

Title 10 of the Code of Federal Regulations Part 20, *Standards for Protection Against Radiation* (10 CFR 20); 10 CFR 40 , *Licensing of Source Material*; and 10 CFR 51, *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions*, authorize the U.S. Nuclear Regulatory Commission (NRC) to regulate the licensing of uranium recovery facilities and to protect workers, the public, and the environment from radiological and non-radiological hazards associated with the operations of such facilities. In response to the increasing number of license applications for uranium recovery facilities (NRC 2011a), the NRC initiated efforts to improve the regulatory framework that supports the licensing of new facilities and expansions of existing facilities, as well as their operation. A significant component of these efforts is the updating and revision of regulatory guides and NUREG-series reports to promote compliance with appropriate regulatory requirements.

In 1980, NRC published Regulatory Guide 4.14, Revision 1 (RG 4.14), *Radiological Effluent and Environmental Monitoring at Uranium* Mills (NRC 1980a). RG 4.14 contains recommendations for the preoperational and operational monitoring of radiological conditions at uranium mills and the collection of technically defensible data to evaluate facility impacts on the environs. The guidance presented by the NRC promotes compliance with 10 CFR 20 and 10 CFR 40 and provides licensees with reporting guidelines to comply with 10 CFR 40.65, *Effluent Monitoring Reporting Requirements*. At the time of its publication, uranium recovery activities were predominantly based on conventional mining and milling. However, in recent decades, uranium recovery operations have shifted towards in situ recovery (ISR) (NRC 2011a).

Reviews of recent license applications have led the NRC to recognize deficiencies in RG 4.14 (ORISE 2011a) with respect to addressing uranium recovery methods other than conventional milling. Revising RG 4.14 to incorporate other uranium recovery methods such as ISR will aid applicants and existing licensees in the development of environmental and effluent monitoring programs (e.g., radiological and non-radiological), and licensing and technical documents (e.g., license applications and environmental and technical reports). It will also provide guidance for the acquisition of technically defensible environmental and effluent data to promote compliance with appropriate regulatory requirements and support subsequent decommissioning activities.

Furthermore, this document addresses both radiological and non-radiological monitoring during the preoperational and operational phases at uranium recovery facilities. Although non-radiological contaminants are included in 10 CFR Part 40 regulations, they were not directly addressed in RG 4.14. The inclusion of non-radiological contaminants is required for uranium mill licensing under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). Under UMTRCA, the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content are 11e(2) byproduct material as defined in that section of the Atomic Energy Act. Specifically, Title 42 of the United States Code (USC), Section 2114, states that "The Commission shall insure that the management of any byproduct material… is carried out in such manner as the Commission deems appropriate to protect the public health and safety and the environment from radiological and non-radiological hazards associated with the processing and with the possession and transfer of such material…." Uranium recovery methods involve chemical extraction of uranium from ore, which releases many other contaminants such as metals from the ore; therefore, the monitoring of non-radiological contaminants in groundwater and surface water are included in the scope of this TBD.

UMTRCA established two programs, Title I and Title II, to protect the public and the environment from uranium mill tailings.

- UMTRCA Title I - Reclamation Work at Inactive Tailings Sites: Under Title I, a remedial action program operated by the U.S. Department of Energy (DOE) was established for uranium mills that were not licensed and largely abandoned at the time the law was enacted (NRC 2012a).

- UMTRCA Title II-Licensed Uranium Recovery Facilities and Mill Tailings Sites: Under Title II, the NRC or Agreement State regulates the mills that were licensed in or after 1978. Title II provides the NRC authority to control radiological and non-radiological hazards. In addition, it provides the U.S. Environmental Protection Agency (EPA) the authority to set generally applicable standards for both radiological and non-radiological hazards and it also provides eventual State or Federal ownership of the disposal sites, under general license from NRC (NRC 2012a).

Title II of UMTRCA provides the basis for the revision of RG 4.14. It is important to emphasize that RG 4.14 focuses and will continue to focus on the preoperational and operational monitoring programs at uranium recovery facilities. However, the revised RG 4.14 will not include guidance for post-operational activities or decommissioning.

Therefore, the current NRC guidance should be revised to provide acceptable instructions for compliance with NRC regulatory requirements (ORISE 2011a). In addition, NRC guidance should be harmonized with other regulatory requirements (e.g., 40 CFR 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*) in order to provide adequate monitoring of uranium recovery operations.

1.2. SCOPE

The NRC requested that Oak Ridge Associated Universities (ORAU), via the Oak Ridge Institute for Science and Education (ORISE) contract, develop a technical basis for revising RG 4.14. This document provides the technical information to assist the NRC in the revision of RG 4.14. It also includes the basis for inclusion of ISR facilities and heap leach facilities, as well as the monitoring recommendations for radiological and non-radiological contaminants for every uranium recovery method. A land use census is discussed and a risk-informed decision-making process is introduced.

The NRC requested that ORAU provide the technical basis for the following topics with respect to RG 4.14:

- Inclusion of uranium recovery methods other than conventional milling
- Improvement of effluent and environmental monitoring programs, including analysis of samples, quality of samples, and other related topics
- Inclusion of non-radiological contaminant monitoring for surface and groundwater
- Inclusion of a land use census for the identification and monitoring of new or modified exposure pathways during a uranium recovery facility operational life cycle
- Application of a risk-informed decision-making process as it relates to environmental monitoring programs
- Revision of guidance to incorporate current regulatory practices and regulations

While mentioned, this work effort excludes the decommissioning of uranium recovery facilities following the termination of the operational phase.

1.3. OBJECTIVE

The objective of this TBD is to provide supporting information for the NRC to consider in the forthcoming proposed revision of RG 4.14. ORAU staff used open literature sources including national and international scientific publications; facility license applications; facility technical and environmental reports; NRC regulatory requirements and guidance documents; as well as guidance documents from relevant regulatory agencies (e.g., Agreement States, EPA) to provide and support the recommended revisions.

1.4. STRUCTURE

The preparation of the technical basis required an extensive review of information on current uranium recovery methods; scientific publications related to the identified issues; license applications; facility technical and environmental reports; International Atomic Energy Agency (IAEA), EPA and NRC guidance documents; as well as EPA and NRC regulatory requirements.

Chapter 1 summarizes the justification for development of the TBD and details the structure of the document. Chapter 2 contains a description of three current uranium recovery methods, a comparison of their characteristics, and monitoring requirements. Chapter 3 contains recommendations, applicability and technical bases for the improvement of Chapter C: *Regulatory Position* of the existing RG 4.14 (i.e., Sections 1–7 including Tables 1-3 and the Appendix), which includes preoperational and operational monitoring programs as well as data collection and analysis. Advances in technology such as computer codes, global positioning systems, solar powered air samplers, and use of all-terrain vehicles for gamma ray monitoring are incorporated into this chapter. Chapter 4 provides information on conducting a land use census identifying new or modified exposure pathways or routes of exposure, and discusses sampling locations as part of the land use census. Several appendices are also included. Appendix A provides a summary of the recommendations included in this TBD to improve RG 4.14. Appendices B and C provide updates to Table 1 and Table 2 of RG 4.14 representing both preoperational and operational monitoring programs and each uranium recovery method. Appendix D provides an update to Table 3 of RG 4.14 pertaining to data reporting. Appendix E extends the Chapter 4 discussion on land use to introduce a risk-informed approach as it relates to environmental monitoring programs for all three principal types of uranium recovery facilities. Appendix E also provides information regarding the chemical toxicity of uranium.

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2. URANIUM RECOVERY METHODS AND THE ENVIRONMENT

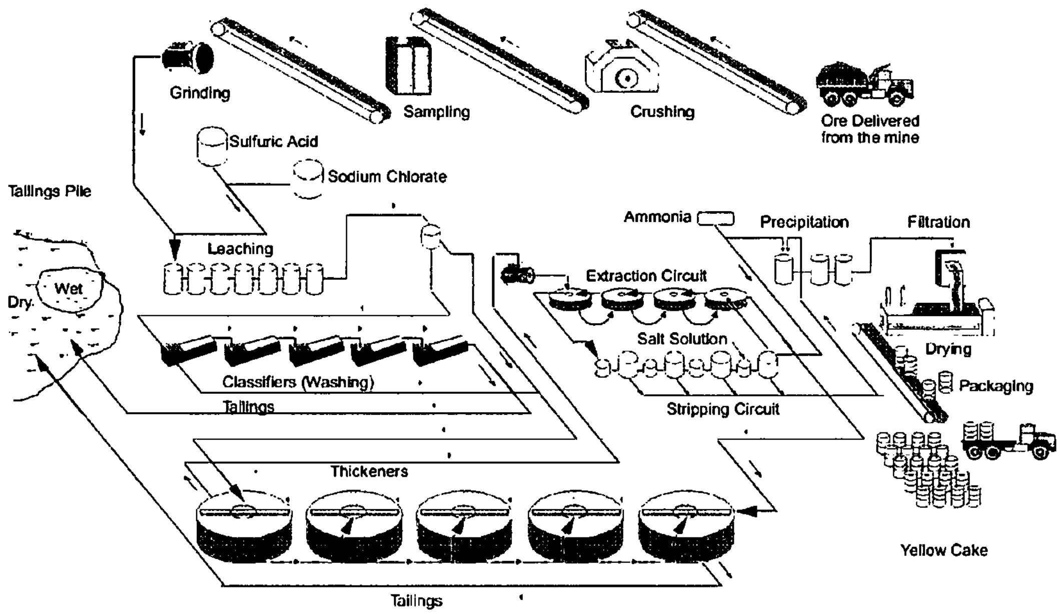
Uranium recovery operations involve extracting and concentrating natural uranium from ore via chemical alterations, a process known as milling. The NRC promulgates, implements, and enforces standards for the licensing and operations of uranium milling facilities in the United States. Currently, there are two primary milling methods, conventional milling and ISR, which are used to extract uranium from ore (NRC 2011b). A third method, heap leaching, has been utilized to cost-effectively extract uranium from low-grade ore and is gaining interest.

Each of these three facility types and associated uranium recovery methods are described in this chapter along with an introductory description of environmental and effluent monitoring.

2.1. CONVENTIONAL URANIUM MILLS

In conventional milling, the uranium ore is mined and transported to the processing facility. Ore is stockpiled at the processing facility to maintain sufficient ore volume to ensure continuous recovery operations. The ore is crushed and ground to produce a grain size which facilitates handling and optimizes contact with leaching agents. Depending on the facility design, strong acids (sulfuric acid) or alkaline solutions (bicarbonates, in most cases) are used to leach the uranium from the ore and concentrate the extracted uranium in solution. The uranium-rich solution is passed through ion-exchange resin beds or a solvent extraction process is used to capture the uranium. The residual leachate/water mixture is usually returned into the extraction process to enhance uranium recovery and minimize waste production. The uranium is subsequently recovered via saline solution washes. The uranium is precipitated and dried to produce uranium oxide compounds (commonly known as yellowcake). Figure 2-1 illustrates a typical conventional uranium mill process.

The type of uranium compounds produced in the process depends on the leachant, precipitation conditions, and drying temperatures. The yellowcake produced at conventional mills can vary in composition from almost pure ammonium diuranate (ADU) to mixtures of uranium oxides (triuranium octoxide, U_3O_8, in most cases), sulfates, nitrates, and sodium compounds (Dennis et al., 1982; ORISE 2011b). Damon et al. (1984) reported that yellowcake powder obtained from one conventional mill contained 82% ADU and 18% U_3O_8, while powder from another sample contained 25% ADU and 75% U_3O_8 (ORISE 2011b).



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

Figure 2-1. Example of Typical Conventional Uranium Mill Process

(source: Energy Information Administration [EIA 1995])

The waste products produced from conventional milling are known as 11e(2) byproduct material and are regulated under the statutory requirements of the Uranium Mill Tailings Radiation Control Act of 1978 [UMTRCA]. UMTRCA defines 11e(2) byproduct material as the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. Uranium mills and wastes are regulated by NRC under 10 CFR 40, Appendix A, *Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for their Source Material Content.* The regulations in 10 CFR 40, Appendix A, incorporate the standards promulgated by EPA for 11e(2) byproduct material in 40 CFR Part 192 as required by UMTRCA. Conventional uranium milling presents numerous radiological and non-radiological hazards (IAEA 2002; NAS 2011). Storing uranium ore may produce airborne particulates or seepage from stockpiles due to climatic conditions (e.g., wind and precipitation) (Energy Fuels 2009). In addition, radon gases emanated from radium decay may present radiological hazards in close proximity to the ore stockpiles and tailings impoundments. Impoundment failures, seepage of contaminants, and incursions of flood water are problems associated with the long-term storage of mill tailings which may transport contaminants to the environment.

2.2. IN SITU RECOVERY FACILITIES

ISR is currently the principal method of extracting uranium from ore (NRC 2011a). ISR is typically used when other milling methods are financially unattractive, environmentally unfavorable, or the ore grade level is low (NRC 2011c). Figure 2-2 illustrates the in situ recovery process. In ISR, a process solution, known as lixiviant, which contains water mixed with an oxidant such as oxygen and/or hydrogen peroxide, as well as complexing agents such as sodium carbonate or carbon dioxide, is injected directly into the subsurface ore-bearing formation through a series of injection wells to solubilize the uranium. The dissolved uranium solution is subsequently pumped to the surface through recovery wells to a processing plant. The recovered fluids, known as pregnant lixiviant, are passed through ion exchange towers, which separate the uranium from solution. The uranium is then recovered from the ion exchange resins via saline washes, concentrated, precipitated, and dried to produce yellowcake. The yellowcake composition produced at ISR facilities mainly consists of uranium tetraoxide (UO_4) and uranium trioxide (UO_3), with little or no U_3O_8 present (Cahill and Burkhard 1990; Crow Butte 2007; EMC 2007; ORISE 2011b). One advantage of ISR methods is that no tailings are generated and the residual solution can be re-circulated through the process to enhance the recovery of uranium and minimize waste generation. The lack of tailings also influences the planning and implementation of the environmental monitoring program (relative to, for example, a conventional uranium mill).

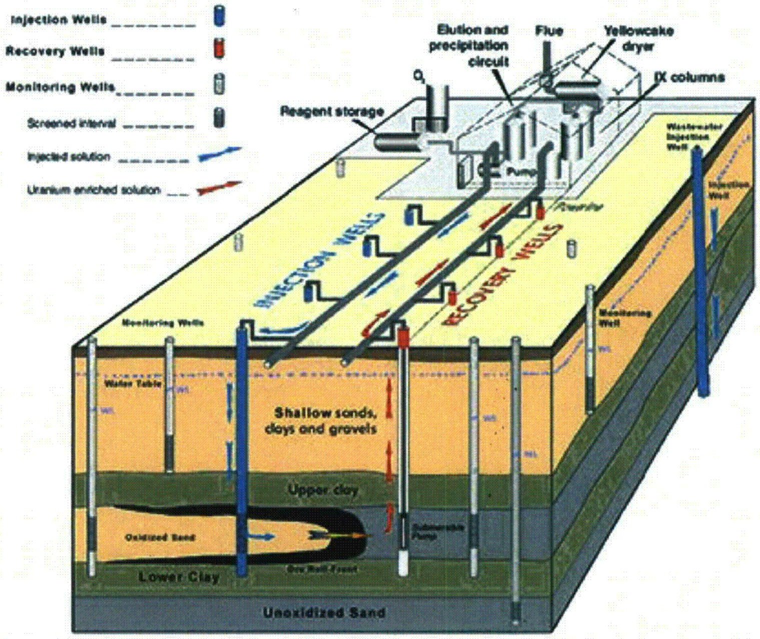


Figure 2-2. Example of In Situ Uranium Recovery Process

(source: International Mining and Milling Corporation [I2M 2012])

2.3. HEAP LEACH FACILITIES

Heap leach is another method utilized to extract uranium from ore. In heap leach uranium recovery, the ore is mined and transferred to a processing facility. Uncrushed ores are placed in a "heap" on an impervious pad of plastic, clay, or asphalt, with perforated pipes under the heap (NRC 2011d). An acid solution (sulfuric acid, in most cases) is sprayed over the ore to leach its uranium contents and concentrate the extracted uranium in solution. The uranium solution is pumped or drained from the heap leach pile to a processing facility. The uranium solution is collected and passed through ion-exchange resin beds. Subsequently, the uranium is recovered from the resins via saline solution washes and dried to produce yellowcake with a composition similar to that obtained by conventional recovery methods. As described in NUREG-0706, heap leach facilities and conventional mills share the same types of environmental concerns. Examples include radon and radioactive particulate releases and tailings-related seepage (NRC 1980b). Figure 2-3 provides a diagrammatic representation of the heap leach recovery process.

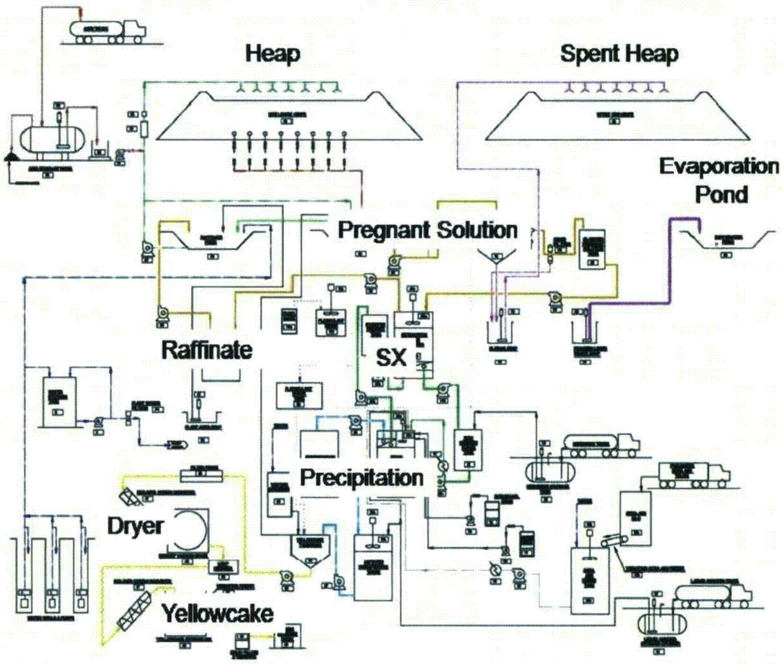


Figure 2-3. Diagrammatic Representation of the Heap Leach Recovery Process (source: Titan Uranium USA, Inc. 2010)

Existing uranium recovery facilities in the United States that utilized heap leach recovery methods are in the process of decommissioning. Recently, NRC has received letters of intent from Titan Uranium USA, Inc. and Uranium Energy Corporation indicating their interest in pursuing licensing of new heap leach recovery facilities in Fremont County, Wyoming, and Cibola County, New Mexico, respectively (NRC 2011a). In addition, Strathmore Resources, U.S. Ltd., has indicated its intent to pursue licensing of a conventional recovery facility, or alternatively, a heap leach facility, in Fremont County, Wyoming.

2.4. COMPARISON OF URANIUM RECOVERY METHODS

Since the issuance of RG 4.14, the NRC and Agreement States have licensed numerous uranium recovery facilities in the United States. These facilities have used a variety of extraction methods to recover uranium from ore. Table 2-1 compares the features of the three main types of facilities—conventional uranium mills, heap leach, and in situ recovery facilities (NRC 2011b). The comparison presented in Table 2-1 is not all-inclusive and only provides the general characteristics of each recovery method. The information in Table 2-1 was excerpted from NRC 2011b; however, additional information and minor editorial changes were made as appropriate.

Table 2-1. Comparison of Uranium Recovery Methods[a]

Feature	Conventional Uranium Mill	Heap Leach Facility	In Situ Recovery Facility
Recovery Method	Physical and chemical process to extract uranium from mined ore.	Physical and chemical process to extract uranium from mined ore that has been piled in a heap.	Chemical process to extract uranium from underground deposits.
Siting/Location	Generally located in the vicinity of the ore body. Mined ore can be trucked from the mine to the mill. The mine can be either a deep underground shaft or a shallow open pit. The NRC does not regulate the mining of ore.	Generally located in the vicinity of the ore body. Mined ore can be trucked from the mine to the mill. The mine can be either a deep underground shaft or a shallow open pit. The NRC does not regulate the mining of ore.	The wellfield area is located within the ore body. The processing plant is typically in the vicinity of the ore body.
Surface Features	Mill building(s), process tanks, tailings impoundment, and evaporation ponds.	Process buildings, heap pile consisting of ore crushed to a size of approximately 1-inch in diameter, with an engineered liner system beneath the heap pile and liquid application on top of the pile.	Wellfield(s) consisting of groundwater injection and extraction wells, header house(s), pipes, processing facility, storage or evaporation pond(s), and deep injection wells for liquid waste. Process facilities for ion exchange, precipitation and drying of uranium.
Approximate Size of Site	Impoundments are limited to 40 acres in size; however, a facility can have multiple impoundments and typically total on the order of hundreds of acres. The proposed licensed area (permit boundary) is within the site boundary; therefore, it is controlled by the licensee.	Heap piles are limited to 40 acres in size; however, a facility can have multiple piles and typically total on the order of hundreds of acres. The proposed licensed area (permit boundary) is within the site boundary; therefore, it is controlled by the licensee.	The proposed licensed area (permit boundary) contains thousands of acres; however, the actual area affected by wellfields or process buildings will be smaller. The permit boundary has controlled areas and unrestricted areas that are not controlled by the licensee.
Wastes Generated	Mill tailings, a sandy material left over from the crushing process, disposed of within an impoundment; pipes, pumps, and other process equipment that cannot be decontaminated.	Heap pile remains in place after processing; pipes, pumps, and other process equipment that cannot be decontaminated.	Liquid waste, which is disposed of in a deep disposal well or through an evaporation system; pipes, pumps, and other process equipment that cannot be decontaminated are sent to an NRC-licensed facility for permanent disposal.
Decommissioning	Demolition of mill and site buildings, final cover system installed over tailings pile, groundwater monitoring.	Demolition of site buildings, final cover system installed over heap pile, groundwater monitoring.	Restoration of groundwater, decommissioning of injection/extraction wells, removal of wellfield infrastructure and processing buildings.
Status at End Use	Site permanently transferred to DOE for long-term care; annual inspections performed.	Site permanently transferred to DOE for long-term care; annual inspections performed.	Site released for unrestricted use when cleanup criteria are met.

[a] Source: NRC 2011b: Uranium Recovery (Extraction) Methods.

2.5. LICENSED AREAS AT URANIUM RECOVERY FACILITIES

With the evolution of uranium recovery methods since 1980, especially with the inclusion of the ISR method, it is important to clarify the distinction between a licensed area and other areas at uranium recovery facilities. The distinction can provide a better understanding to applicants and licensees on the placement of monitoring stations as part of the environmental monitoring programs particularly at ISR facilities. This distinction may not be as much a concern at conventional mills and heap leach facilities. The following areas are briefly described in this section: licensed area, site boundary, controlled area, restricted area, and unrestricted area.

2.5.1. Conventional Uranium Mills and Heap Leach Facilities

For conventional mills and heap leach facilities, the licensed area (permit boundary) is clearly defined and has a fence as a physical barrier to limit access. This fenced area corresponds to the site boundary, and it is an area controlled by the licensee. These three areas: licensed area, site boundary, and controlled area are essentially the same. Processing facilities and supporting infrastructures are located within the fenced site boundary. The relative size of the licensed area at these facilities is small in comparison to ISR facilities. Other areas, such as restricted areas, are located within the controlled area. Unrestricted areas are located outside the site boundary; within the unrestricted areas there could be, for example, residential, recreational, ranching, or farming areas. Also, it is important to be cognizant that these facilities can be (and some are) located at or near national forests, state parks, or other tourist attractions.

The definitions for some of the areas are available in 10 CFR 20.1003, NRC Regulatory Guide (RG) 4.1 (NRC 2009a), and NRC online glossary (NRC 2012b), as described below, with minor edits made as applicable. The definitions are as follows:

- A *controlled area* at a uranium recovery facility is an area outside a restricted area but within the site boundary, which the licensee can limit access for any reason (10 CFR 20.1003, NRC glossary).

- A *site boundary* means that line beyond which the land or property is not owned, leased, or otherwise controlled by the licensee (10 CFR 20.1003, RG 4.1).

- A *restricted area* means an area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials (10 CFR 20.1003).

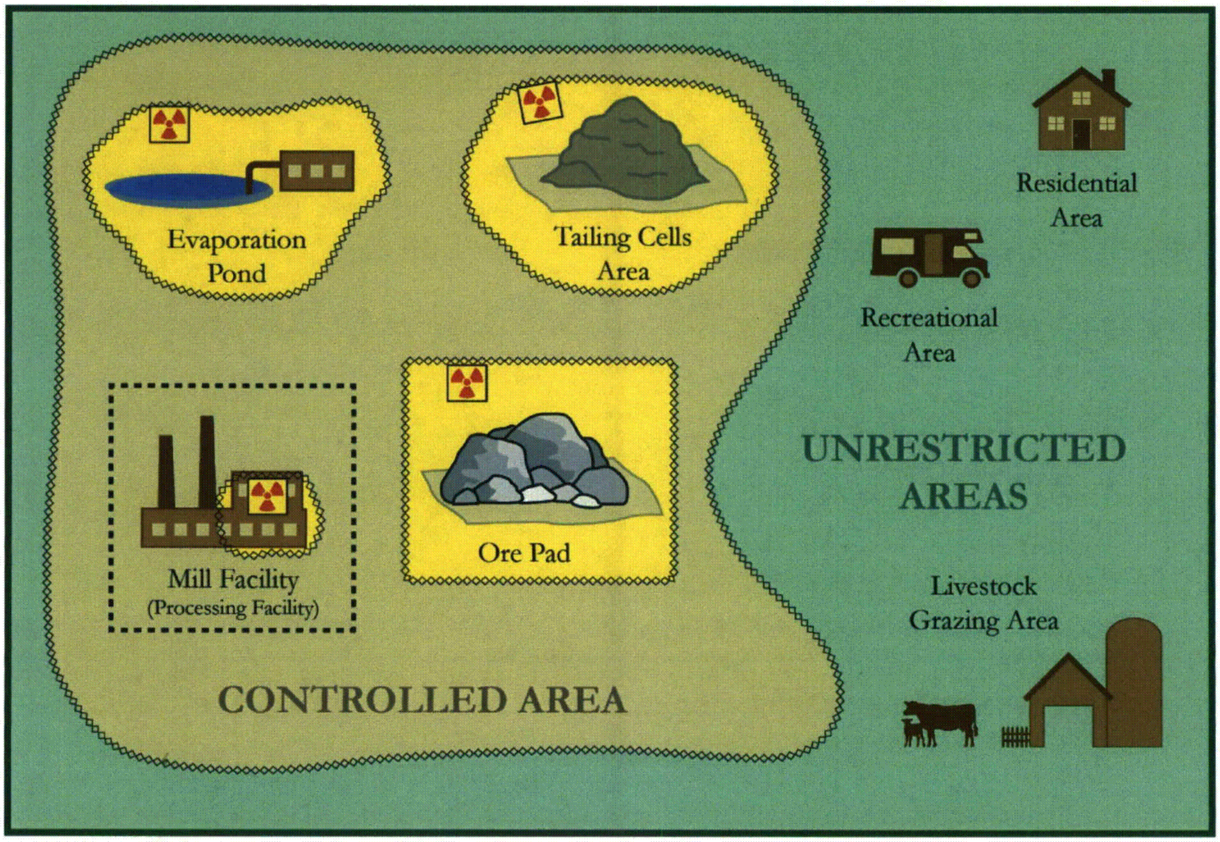
- An *unrestricted area* means an area, access to which is neither limited nor controlled by the licensee (10 CFR 20.1003, RG 4.1).

- No specific definition for licensed area was found in the NRC glossary, 10 CFR 20, RG 4.1, or 10 CFR 40. However, 10 CFR 20.1003 defines *license* and *licensee* as follows:

    - A *license* means a license issued under the regulations in parts 30 through 36, 39, 40, 50, 60, 61, 63, 70, or 72 of this chapter.

    - *Licensee* means the holder of a license.

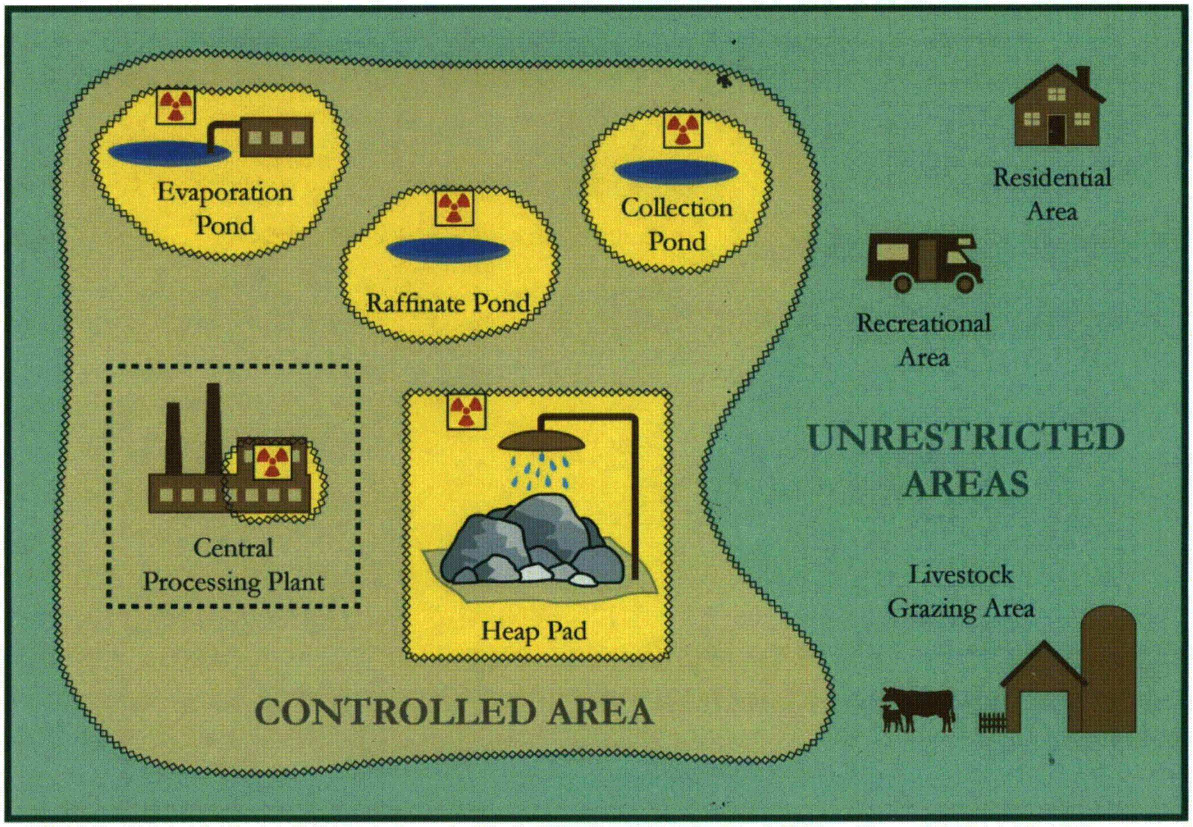
The following layouts (Figures 2-4 to 2-5) illustrate the licensed area, site boundary, controlled areas, and unrestricted areas for conventional mills and heap leach facilities respectively. Examples of other areas within the unrestricted areas are also included. These layouts are not intended to be all-inclusive; the purpose is to provide a generic illustration of the different areas.



LEGEND

- Licensed Area, Site Boundary, and Controlled Area
- Fence
- Facility Boundary
- Restricted Area
- Unrestricted areas are those areas to which access is neither limited nor controlled by the licensee.

Figure 2-4. Layout of a Hypothetical Conventional Mill Facility



LEGEND

- Licensed Area, Site Boundary, and Controlled Area
- Fence
- Facility Boundary
- Restricted Area
- Unrestricted areas are those areas to which access is neither limited nor controlled by the licensee.

Figure 2-5. Layout of a Hypothetical Heap Leach Facility

2.5.2. In Situ Recovery Facilities

The licensed area (permit boundary or site boundary) at ISR facilities contains thousands of acres (which are not surrounded by a fence); however, the actual area affected by wellfields or process buildings (e.g., central processing plant (CPP), satellite facilities, and any other facility that handles, stores, or processes large quantities of source materials) will be smaller. The licensed area has controlled areas and unrestricted areas. The unrestricted areas are not controlled by the licensee and are accessible to the public.

The facility boundary should be the fenced perimeter of the process buildings (e.g., CPP, satellite facilities and any other facility that handles, stores, or processes large quantities of source materials). Other areas such as restricted areas are located within the controlled areas. Unrestricted areas are located within the licensed areas, and within the unrestricted areas there could be, for example, residential, recreational, ranching or farming areas. Also, it is important to be cognizant that these facilities can be (and some are) located at or near national forests, state parks, or other tourist attractions.

The following layout (Figure 2-6) illustrates the licensed area or site boundary, controlled areas, and unrestricted areas for ISR facilities. Examples of other areas within the unrestricted areas are also included. This layout is not intended to be all inclusive; the purpose is to provide a generic illustration of the different areas.

At ISR facilities, facilities that support uranium processing are considered controlled areas where security fencing controls access. These facilities can include a central uranium processing facility or CPP, header houses to control flow to and from the wellfields, satellite facilities that house ion-exchange columns and reverse osmosis equipment for groundwater restoration, and ancillary buildings that house administrative and support personnel. Select areas around header houses and well heads are fenced to prevent livestock grazing (NUREG-1910 Vol 1, NRC 2009b).

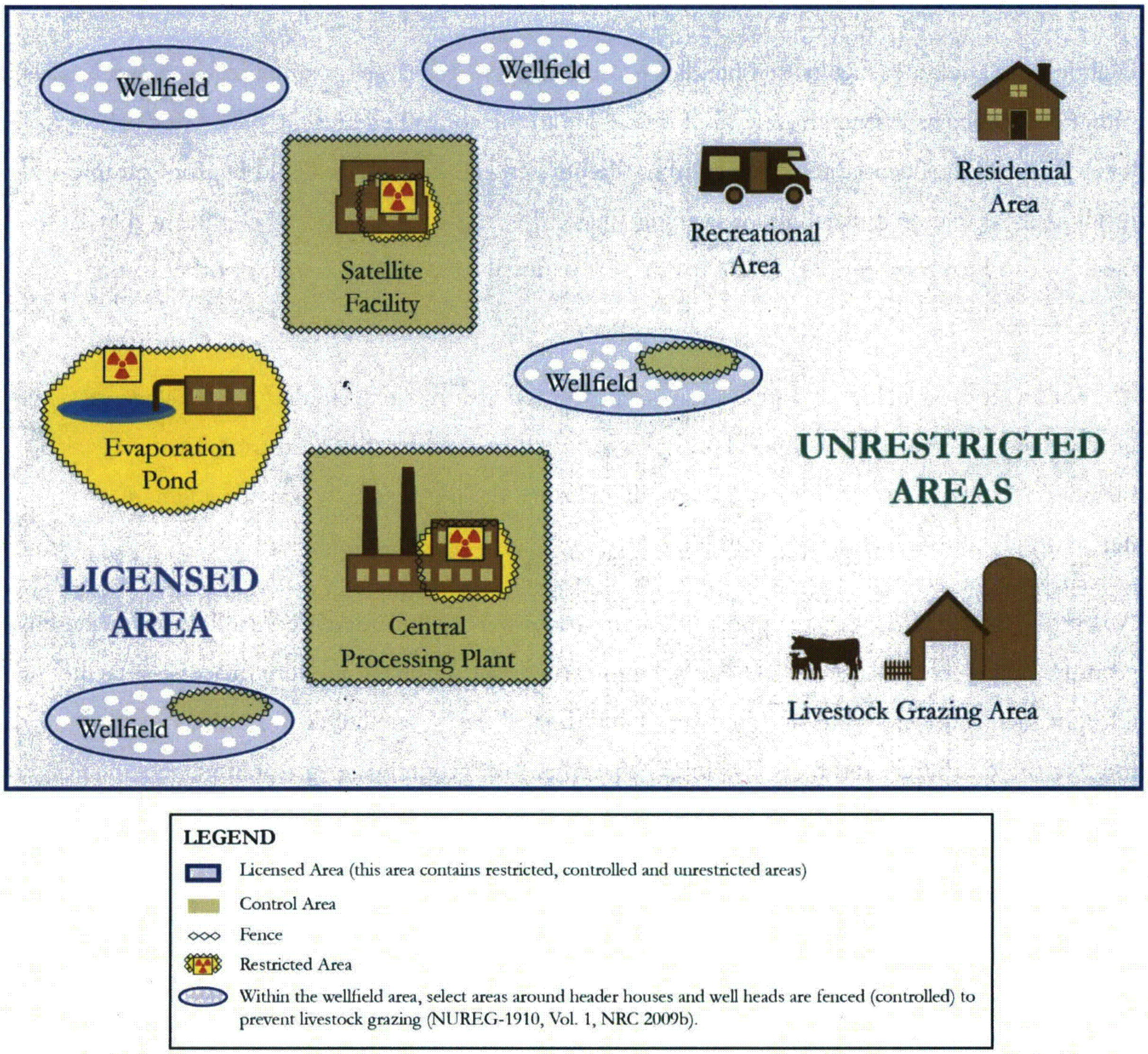


Figure 2-6. Layout of a Hypothetical ISR Facility

2.6. Environmental and Effluent Monitoring at Uranium Recovery Facilities

Each type of uranium recovery facility potentially generates quantities of radiological and non-radiological (chemical) contaminants during normal processing activities. These contaminants may be released to the environs, particularly to unrestricted areas around the facility. Consequently, individual members of the public can be potentially exposed to these contaminants (e.g., primarily from air and water). To protect the public and the environment, the NRC requires environmental and effluent monitoring programs at uranium recovery facilities to ensure that the contaminants released to unrestricted areas satisfy the regulatory limits in 10 CFR 20 (including the "as low as reasonably achievable" or "ALARA" requirements in 20.1101, *Radiation protection programs)*, 40 CFR 190, and comply with the provisions in 10 CFR 40 and other applicable standards. It is important to note that the NRC limits the monitoring of non-radiological contaminants to groundwater and surface water under UMTRCA as discussed in Section 1.1.

2.6.1. Environmental Monitoring

Environmental monitoring involves the collection and analysis of samples or measurements to identify and quantify potential contaminants present in the environs. As described in 10 CFR 40, Appendix A, Criterion 7, a preoperational environmental monitoring program is required at least one full year prior to any major site or facility construction and operation in order to gather detailed baseline data of the site's environmental conditions. An operational environmental monitoring program is required to continue during construction and operation of the facility to ensure compliance with applicable standards and regulations; and to verify facility control systems used for controlling the release of radiological and non-radiological (chemical) contaminants to the environment. An increase in the levels of contaminants in the environment as a result of uranium recovery operations can impact the public through different exposure pathways.

Because 10 CFR 40, Appendix A, Criterion 7 requires a "baseline" assessment during the preoperational monitoring phase, a distinction is made in this TBD between "baseline" and "background." These words are often used interchangeably and may create confusion as to what is intended. The word "baseline" will be used throughout this document to include all environmental and socioeconomic factors associated with monitoring the environs during the preoperational phase. In this TBD "background" is considered to be a subcategory of "baseline." A more complete discussion of baseline versus background is provided in Chapter 3.

In the context of this TBD, environmental monitoring includes the collection and analysis of the following: air (particulates and radon), water (surface and groundwater), soil (surface and subsurface), sediment (associated with surface waters), vegetation, food crops, and edible fish. In addition, direct gamma radiation measurements are taken to assess environmental exposure and dose rates primarily to workers at uranium recovery facilities and members of the public. The type of facility (e.g., ISR versus conventional mill) will influence the design and subsequent implementation of the environmental monitoring program.

2.6.2. Effluent Monitoring

Effluent monitoring involves the collection and analysis of samples or measurements of liquid and gaseous effluents to identify and quantify potential contaminants. Per RG 4.1, effluents are defined as the liquid or gaseous wastes containing facility-related, licensed radioactive materials, released at the site boundary which may enter unrestricted areas. The effluent releases from routine uranium recovery operations can either be airborne (particulate or gaseous) or waterborne. Because these environmental releases can impact the public and the environs, an effluent monitoring program is established at uranium recovery facilities to provide data on the contaminants potentially present in air and liquid effluents. Per 10 CFR 20.1302, *Compliance with Dose Limits for Individual Members of the Public*, licensees shall perform surveys (as appropriate per the regulation) of radiation levels in unrestricted and controlled areas and radioactive materials in effluents released to unrestricted and controlled areas to demonstrate compliance with the dose limits for individual members of the public in 20.1301. Subpart F, *Surveys and Monitoring*, of 10 CFR 20.1501, *General*, requires a licensee to perform a radiological survey to evaluate the radiological hazard from radioactive material in the air, soil, or water. A *survey* is defined in Part 20 as a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present. 10 CFR 40.65, *Effluent Monitoring Reporting Requirements*, requires the submission of an annual report specifying "the quantity of each of the principal radionuclides released to unrestricted areas in liquid and in gaseous effluents during the previous six months of operation, and such other information as the Commission may require to estimate maximum potential annual radiation doses to the public resulting from effluent releases." 10 CFR 40, Appendix A, Criterion 8, requires that "airborne effluent releases are reduced to levels as low as reasonably achievable."

3. DEVELOPMENT OF TECHNICAL BASIS

This chapter contains recommendations, applicability, and technical bases for the improvement of Chapter C: *Regulatory Position* (Sections 1–7 including Tables 1–3 and the Appendix), of the existing NRC RG 4.14, Revision 1. Preoperational and operational monitoring aspects are discussed. One of the most important changes is to include specific guidance for ISR and heap leach facilities as RG 4.14 was originally developed solely for conventional uranium mills. The importance of collecting meteorological data prior to the onset of the preoperational monitoring phase is also discussed. For ease of reference, sections of the *Regulatory Position* in the current guide were excerpted verbatim and included in this chapter, followed by recommendations, applicability to each type of uranium recovery facility, and justifications in support of the revision of RG 4.14.

It should be noted that when the NRC is referenced in this document, it is understood that this can encompass other cognizant regulatory authorities (such as Agreement States).

3.1. RG 4.14 REGULATORY POSITION

Meteorological Data Prior to Preoperational Monitoring

Collecting onsite meteorological data prior to the start of the preoperational monitoring phase has been identified as a need in the revision of NRC RG 4.14. This approach was not utilized in the current regulatory guidance, but is considered important in the determination of preoperational sampling locations of environmental media, especially for air and radon. Onsite data is now emphasized due to concerns associated with the use of meteorological data from remote locations (e.g., an airport monitoring station many miles from the site). For that reason, the collection of onsite meteorological data for a period of at least 12 consecutive months is specifically recommended later in this document.

3.1.1. Preoperational Monitoring

<u>Current Guidance</u>

Section 1 of the current guidance states the following for a preoperational monitoring program:

> *An acceptable preoperational monitoring program is described below and summarized in Table 1. At least twelve consecutive months of data, including complete soil sampling, direct radiation, and radon flux data,*

should be submitted to the NRC staff prior to any major site construction. A complete preoperational report with twelve consecutive months of data should be submitted prior to beginning milling operations. Prior to the start of local mining operations, if possible, monitoring data, including airborne radon measurements, should be submitted to the NRC staff.

Applicants may propose alternatives to this preoperational program. However, equivalent alternatives should be proposed for the operational program so that the programs remain compatible.

Recommendations, Applicability, and Justifications/Discussions

It is recognized that some of the terminology (e.g., mill site, milling operations, tailing areas, and tailing impoundments) used in the current guidance may not be applicable to in situ or heap leach facilities and no technical justification for changing the terminology is included in this document. However, the revised guidance should include appropriate terminology as applicable for each facility type. The following recommendations, applicability, and justifications are provided to enhance the preoperational monitoring section in RG 4.14.

A. Recommendation: The words "mining operations" should be changed to "uranium recovery."

Applicability: This recommendation is applicable to all uranium recovery facilities

Justification/Discussion: The terminology "uranium recovery" should be substituted for "mining operations" in the next revision of NRC Regulatory 4.14. The NRC does not regulate mining.

The term "extraction" as originally used in the TBD has several meanings and could be subject to misinterpretation when applied to each of the three types of uranium recovery facilities (conventional mills, heap leach, and in situ recovery). The fundamental issue lies in correctly recognizing when the uranium extraction process begins at each facility. For example, ISR facility applicants may interpret the term "extraction" to begin at the point where uranium is collected in the ion-exchange columns from the pregnant lixiviant onto the resin. At heap leach facilities, the extraction may begin at the point where the acid solution is sprayed onto the uranium ore.

To minimize misinterpretation, adoption of the more general term, "uranium recovery" is now recommended for use in the revised regulatory guidance. The term may be defined, for example, at the point where the raw uranium ore material is separated and processed (as is the case at conventional and heap leach facilities) or a chemical agent is introduced into the process (ISR).

B. **Recommendation**: The difference between the terms "background" and "baseline" should be addressed in the future revision of RG 4.14.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: To promote consistency (and minimize confusion) in the revision of RG 4.14, the terms "baseline" and "background" should be defined (The current guide does not define these terms.) These terms have different meanings, but have been used interchangeably by applicants or licensees. Based on discussions with NRC staff, applicants or licensees may have intended in some cases to equate "baseline" and "background" while in other cases, a slightly different meaning may have been intended. For example, during preoperational monitoring, "baseline" and "background" could each be intended to represent natural ambient conditions. In other cases, such as new licensing of an old(er) facility, "baseline" could represent the current ambient conditions, which may be different from "background" prior to any operations.

The word "baseline" will be used throughout this document to include all environmental and socioeconomic factors associated with monitoring the environs during the preoperational phase. In this TBD "background" is considered to be a subcategory of "baseline."

<u>"Background": Background Radiation (also referred to as Background), Non-Radiological Background, and Background Sample</u>

The NRC regulations (e.g., 10 CFR 20 and 10 CFR 40) and NRC guidance documents reviewed (e.g., NUREG-0706, NRC 1980b; NUREG/CR-6733, NRC 2001a; NUREG-1569, NRC 2003a; NUREG-1748, NRC 2003b; RG 4.14, NRC 1980a; RG 4.1, NRC 2009a) use the terms "background" and "baseline." Consequently, defining these terms is important to provide clarification to the applicants and licensees. The definition of "background radiation" (typically referred to as "background") is cited in 10 CFR 20.1003 of the NRC regulations. As stated in

10 CFR 20.1003: "*background radiation" means radiation from cosmic sources; naturally occurring radioactive material, including radon (except as a decay product of source or special nuclear material); and global fallout as it exists in the environment from the testing of nuclear explosive devices or from past nuclear accidents such as Chernobyl that contribute to background radiation and are not under the control of the licensee. "Background radiation" does not include radiation from source, byproduct, or special nuclear materials regulated by the Commission.* With regard to preoperational monitoring, background radiological characteristics should be established (per 10 CFR 40) during the preoperational monitoring phase prior to any major site construction (as part of the site characterization). It should be noted that this definition is limited to radiological background and excludes non-radiological background. Non-radiological background, as it relates to the future revision of RG 4.14, can be defined as the existing concentration of chemical constituents in ground water and surface water present in the environment prior to site development.

Background is also a term that is frequently used to refer to a control sample. The definition of "background" is not to be confused with the "background location" or "background sample"; in this instance background refers to the control location where the environmental levels or conditions of radiological and non-radiological constituents are lowest. (While radiological instrumentation is used to detect background radioactivity, a discussion on instrument background is excluded from this section.) Usually, control sample locations are upgradient and upwind, but such may not be the case for all media (e.g., radon). For instance, an air sample representing "background conditions" at a site should be collected at a remote location; in general, a proper location would be in the least prevalent wind direction from the site and unaffected by mining or other milling operations.

"Baseline"

The definition of "baseline" was not found in the NRC regulations (e.g., 10 CFR 20 and 10 CFR 40), the NRC website, or NRC guidance documents (e.g., NUREG-0706, NUREG/CR-6733, NUREG-1569, NUREG-1748, RG 4.14, RG 4.1). Although a specific NRC definition was not found, the term "baseline" used in 10 CFR 40 Appendix A, Criterion 7 and NRC guidance documents is associated with the preoperational monitoring phase at a site. Criterion 7 states: "*At least one full year prior to any major site construction, a preoperational monitoring* *program must be conducted to provide complete baseline data on a milling site and its environs....*" In the absence of an NRC definition or detailed information about the word "baseline" specific to preoperational environmental monitoring, the search was expanded to other regulatory authorities such as the International Atomic Energy Agency (IAEA), the U.S. Department of Energy, and the U.S. Environmental Protection Agency (EPA). The IAEA describes (in detail) the term "baseline" and the information is introduced in this document for consideration.

Several IAEA publications discuss "baseline data collection programs" and "baseline radiological conditions" in terms of preoperational studies. These publications include the following: IAEA 1997, IAEA 2005, and IAEA 2010. Each of these IAEA publications contain similar information about baseline data collection as it relates to preoperational studies; however, the information that appears more complete and relevant to this document is specifically taken from IAEA Nuclear Energy Series Technical Report No. NF-T-1.2, *Best Practice in Environmental Management of Uranium Mining* (IAEA 2010). This IAEA report specifies that baseline information is necessary to characterize both the physical and social environment, before the development of a project. Usually, baseline studies are performed to accomplish the following:

- Collect data about predevelopment conditions
- Document information on predevelopment conditions
- Integrate information into project supporting documents (e.g., monitoring and remediation plans)

"Pre-development" could be interpreted as equivalent to the preoperational phase. Per the IAEA, baseline information is used for making impact predictions and for assessing project alternatives and mitigation measures. In the context of RG 4.14, "impacts" could refer to environmental impacts, and "project alternatives" and "mitigation" could refer to alternative monitoring practices or corrective actions. Baseline information may also be used in other programs, e.g., remediation, restoration and monitoring plans, as a comparison against future changes (IAEA 2010).

The collection of baseline information may include field studies, literature reviews of existing documentation, database searches and conducting interviews within communities adjacent to the proposed project area (IAEA 2010). As stated in IAEA 2010:

...The scope of a baseline data collection program must clearly define the baseline parameters required. Examples of baseline data include but are not limited to those outlined below. It must be noted that the data sets required will be site specific as is the timeframe over which they are collected. Often information may need to be collected at different times of the year to account for seasonal variation.

- *Socioeconomic characterization:*
  - *Current and historic land uses;*
  - *Archeological and heritage surveys;*
  - *Identification of all stakeholders;*
  - *Identification of beneficial uses of land and water;*
  - *Documentation of regulatory regime under which the project would operate.*
- *Environmental characterization:*
  - *Hydrological and hydrogeological conditions;*
  - *Geological and geochemical characterization;*
  - *Flora and fauna surveys;*
  - *Climate data;*
  - *Soil surveys;*
  - *Radiological surveys; and*
  - *Contaminated site assessments.*

Baseline data collection is undertaken in order to adequately document the environmental conditions that exist at a site prior to commencing activities that may alter the existing environment. Accurate and comprehensive baseline data will enable a company to reliably demonstrate the environmental and social impacts and performance of the operation as well as remediation works undertaken. Furthermore, it is only with good baseline data that early detection of deviations from expected or predicted performance can be identified. Early detection of such deviations in itself is a best practice principle.

Generally, baseline data collection is done in conjunction with the exploration or conceptual design stage of a project....

Although it is not specifically mentioned in IAEA 2010, "radiological and non-radiological background" are parameters of the baseline environmental site characterization conducted prior to site development. NUREG-1569 (NRC 2003a), Section 2.0 "Site Characterization," includes "radiological and non-radiological background" as parameters to be assessed as part of the site characterization. NUREG-1569 includes the following parameters: Site Location and Layout; Uses of Adjacent Lands and Waters; Population Distribution; Historic, Scenic, and Cultural Resources; Meteorology; Geology and Seismology; Hydrology; Ecology; Background Radiological Characteristics; and Other Environmental Features (e.g., Background Non-Radiological Characteristics). Therefore, the initial site characterization should encompass environmental and socioeconomic parameters as part of the baseline data.

Summary

Baseline parameters should be assessed by applicants for inclusion in the license application and associated technical and environmental reports. The future RG 4.14 should include guidance related to the assessment of relevant baseline parameters such as meteorology; radiological background characteristics; non-radiological (chemical) background characteristics specifically for ground water and surface water; and land use. Meteorology should be assessed for at least 12 consecutive months prior to evaluating the site's existing radiological background characteristics (e.g., in air) as part of the baseline established during the conduct of the preoperational monitoring program. The evaluation of site-specific background radiological characteristics include measurements of radioactive materials occurring in important species of vegetation, food and fish; soil; air (particulates and radon); ground water; and surface water that could be affected by the proposed operations. The evaluation of non-radiological (chemical) background characteristics includes measurements of chemical constituents in ground water and surface water.

Typically, "baseline" and "background" are associated with preoperational monitoring. Therefore, the term "baseline" in the future RG 4.14 should be used in reference to preoperational activities. In this document, background is considered to be a subcategory of "baseline." However, there may be instances where new licensing of an old(er) facility establishes a "baseline" that represents the current ambient conditions that may differ from "background" prior to the start of operations. In such cases the applicant should clearly state that baseline represents the current ambient conditions. Additionally, it may be interpreted that background is affected by nature and baseline by humans.

C. **Recommendation**: The current guidance should be expanded to include environmental monitoring for non-radiological contaminants in ground water and surface water.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance is limited to monitoring radiological contaminants in a variety of environmental media (air; water; vegetation, food, and fish; and soil and sediment). The guidance should be expanded to address both radiological and non-radiological monitoring during the preoperational (and operational) phases of the uranium recovery facilities. Uranium recovery methods involve chemical extraction of uranium from ore which may release non-radiological contaminants into the extraction fluids. The most likely transport medium for these non-radiological contaminants is water; therefore, the monitoring of non-radiological contaminants in ground water and surface water is necessary.

The authority to regulate non-radiological contaminants in uranium recovery is addressed in Uranium Mill Tailings Radiation Control Act (UMTRCA) which defines 11e(2) byproduct material (as initially defined in the Atomic Energy Act) as the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. In particular, 42 USC 2114 of UMTRCA states that the Commission shall ensure that the management of any byproduct material is carried out in such manner as the Commission deems appropriate to protect the public health and safety and the environment from radiological and non-radiological hazards associated with the processing and with the possession and transfer of such material. NRC complies with UMTRCA through the regulations found in 10 CFR Part 40 Appendix A. In addition, the National Environmental Policy Act (NEPA) of 1969 reinforces NRC authority found in the UMTRCA statutes by requiring NRC to assess both radiological and non-radiological environmental impacts for sites licensed by the NRC as described in NUREG-1569 (NRC 2003a).The NRC complies with NEPA through regulations promulgated in 10 CFR Part 51, *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions.*

The non-radiological contaminants (e.g., hazardous chemical constituents) that should be included in the preoperational monitoring program are those contaminants required to be monitored by regulatory agencies and anticipated to be generated during site operations. In the case of uranium recovery facilities, ground water and surface water pathways are of particular significance. The technical basis for emphasizing these pathways over all other environmental pathways is supported by the drinking water limits found in 10 CFR 40 Appendix A, Criterion 5 (Paragraph 5C, *Maximum Values for Ground-Water Protection*) and secondary ground water protection standards found in Criterion 13. Criterion 5 lists individual hazardous constituents (with associated maximum concentrations) while Criterion 13 lists hazardous constituents "for which standards must be set and complied with if the specific constituent is reasonably expected to be in or derived from the byproduct material and has been detected in ground water." Criterion 13 is based on 40 CFR 192, but is not an exhaustive listing (per the NRC). These criteria also serve as the technical basis for surface pathways.

ORAU did not identify a compelling technical basis to include non-radiological contaminants in environmental pathways other than ground water and surface water sources.

D. Recommendation: Applicants should perform a more representative and comprehensive preoperational baseline by continuously monitoring existing onsite background radiological and non-radiological environmental media for a period of two years. R.G. 4.1

Radon workshop April 30, 2010

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The NRC regulations in 10 CFR Part 40, Appendix A, Criterion 7 require at least one full year of preoperational monitoring (prior to any major site construction), also equivalent to at least the amount of time recommended in the current RG 4.14. A longer monitoring period is now recommended for applicants to establish a more defensible, representative, and complete baseline assessment by continuously monitoring existing onsite air and water conditions for two years (e.g., to establish the presence of any temporal variation). This revised approach would provide the applicants (and the NRC) with a more complete characterization of existing background radiological and non–radiological (specifically ground water and surface water) environmental conditions at the site. The exception to this recommendation is that vegetation, food, fish, soil, sediment, and direct radiation monitoring should continue to be conducted at specified frequencies during the preoperational phase; e.g., soil samples should be collected once prior to construction and sampling should be repeated for each location disturbed by site excavation, leveling or contouring.

A partial basis for an extended preoperational monitoring period beyond what is currently recommended in RG 4.14 is based on the potential for significant variability in background radon concentrations. Documenting that variability by monitoring for additional time, or at additional locations, is now recommended.

To support this approach, prior to the onset of the preoperational monitoring phase, meteorological data should be collected for a period of at least 12 consecutive months to support the establishment of air monitoring station locations and number of samples.(Refer to Recommendation 3.1.1.1.A for details.) At the end of the 12 month period, the applicant would initiate the preoperational period; monitoring and sampling of environmental media would continue for two years. Applicants would be encouraged to submit a license application to NRC following the collection of meteorological data and during the initiation of the preoperational phase. A total of three years (one year for the meteorological period and two years for the preoperational monitoring phase) would be anticipated. Prior to license approval, a final preoperational report would be submitted to the NRC.

The preoperational monitoring conducted prior to any major uranium recovery site construction should provide sufficient detail to allow a reasonable future comparison of the data collected after site construction and operation. Adequate preoperational monitoring is essential to establish a background that may be used to detect any natural increase or site-related release of contaminants beyond site boundaries during the operational period. Furthermore, once the facility terminates operations, the background measurements will serve as the starting point to return the site to unrestricted use (NAS 2011).

E. Recommendation: Table 1 of the current guidance, *Preoperational Radiological Monitoring Program for Uranium Mills,* should be updated to reflect the modifications recommended in this document.

Additionally, for ease of reference, separate tables (for each facility) summarizing the preoperational radiological and non-radiological monitoring programs should be included.

Applicability: These recommendations are applicable to all uranium recovery facilities.

Justification/Discussion: Table 1 summarizes the preoperational radiological monitoring program for conventional uranium mills. Due to operational differences and potential contaminants generated at each type of uranium recovery facility, separate tables summarizing the preoperational radiological and non-radiological monitoring programs should be generated for each facility (as applicable). Implementing this recommendation as a planning component of the preoperational program should provide the applicants with additional information prior to the onset of the operational phase. Each table should also include the recommendations provided in this document, as appropriate.

The preoperational radiological monitoring programs for conventional mills and heap leach facilities, and in situ recovery facilities are summarized in Tables B-1 and B-2 respectively, of Appendix B. Furthermore, Tables B-3 and B-4 of Appendix B describe the preoperational non-radiological monitoring program for conventional mills and heap leach facilities, and ISR facilities, respectively. As identified previously, non-radiological monitoring programs would include ground water and surface water only.

F. **Recommendation:** Applicants should continue to propose alternative approaches to the preoperational monitoring program that are equivalent to (compatible with) the operational program.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The preoperational monitoring strategies cited in the current guidance for a variety of environmental media are not requirements-based. In the next revision of RG 4.14, the NRC should continue to offer flexibility to the applicants in developing and implementing a preoperational monitoring program acceptable to NRC staff. Monitoring approaches, for example, may differ from those in the revised guidance if accessibility to newer technology becomes available and "acceptable" industry practices evolve. If the applicants decide to propose alternatives to the preoperational program presented in the revised guidance, a justification or technical basis will still be required by the NRC, especially to verify compatibility with the operational program.

G. **Recommendation:** Methods to calculate public doses from proposed operations should be determined by the applicants and submitted for evaluation to the NRC. This should be included in the NRC RG 4.14 revision.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The revised guidance may be improved by specifying that applicants should determine methods to calculate public doses from proposed operations when environmental data are unavailable. Applicants may use predictive models to evaluate doses to the public from facility releases; for instance, MILDOS-AREA, an acceptable computer code developed by Argonne National Laboratory for uranium mill facilities, may be used to calculate offsite doses to individuals from airborne radioactive materials released from these facilities (NRC 2003a). MILDOS-AREA estimates offsite doses from airborne radionuclide emissions from the uranium series. This code is the primary tool used by the NRC staff and applicants to evaluate radiological impacts from uranium recovery operations. The exposure pathways considered in MILDOS-AREA are inhalation; external exposure from groundshine and cloud immersion; and ingestion of vegetables, meat, and milk (NRC 1981a). However, this code should not be the sole method used to demonstrate compliance with public dose limits.

Because it may not be practical or reasonable to directly measure the dose to members of the public within an 80 km radius surrounding an emission source, MILDOS-AREA or other modeling codes or methods acceptable to the NRC should be used to estimate offsite radiation doses.

MILDOS-AREA is currently being upgraded to include a corrected dusting algorithm and other changes such as updated dose conversion factors, graphical user interface features, and revised regulatory guidance. The most current version available on the MILDOS-AREA website should be used.

MILDOS-AREA is listed as an example of a method used for estimating doses from airborne radioactive material releases from a uranium recovery facility. However, it is important for the applicant to understand its limitations since this code does not consider the ground water pathway. The applicant is responsible for selecting adequate methods for calculating doses to the public from the pathways of concern (e.g., air and water) and a justification should be included for review by the NRC.

3.1.1.1. Air Samples

Current Guidance

Section 1.1.1 of the current guidance states the following for the preoperational sampling of air:

> *Air particulate samples should be collected continuously at a minimum of three locations at or near the site boundary. If there are residences or occupiable structures within 10 kilometers of the site, a continuous outdoor air sample should be collected at or near the structure with the highest predicted airborne radionuclide concentration due to milling operations and at or near at least one structure in any area where predicted doses exceed 5 percent of the standards in 40 CFR Part 190. A continuous air sample should also be collected at a remote location that represents background conditions at the mill site; in general, a suitable location would be in the least prevalent wind direction from the site and unaffected by mining or other milling operations.*
>
> *Normally, filters for continuous ambient air samples are changed weekly or more often as required by dust loading.*
>
> *The sampling locations should be determined according to the projected site and milling operation. Preoperational sampling locations should be the same as operational locations. The following factors should be considered in determining the sampling locations: (1) average meteorological conditions (windspeed, wind direction, atmospheric stability), (2) prevailing wind direction, (3) site boundaries nearest to mill, ore piles, and tailings piles, (4) direction of nearest occupiable structure (see footnotes of Tables 1 and 2), and (5) location of estimated maximum concentrations of radioactive materials.*
>
> *Samples should be collected continuously, or for at least one week per month, for analysis of radon-222. The sampling locations should be the same as those for the continuous air particulate samples.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the preoperational air sampling program in RG 4.14.

A. **Recommendation:** Applicants should evaluate meteorological conditions, using onsite monitoring stations, for at least 12 consecutive months prior to establishing the preoperational air sampling program to support the determination of appropriate air sampling locations.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance mentions, but does not particularly emphasize, the importance of assessing the onsite meteorological conditions before the initial environmental air sampling at the site. It is important for applicants to gather data concerning the meteorological conditions at the site prior to establishing a preoperational air sampling program for air particulates and radon. Meteorological data is useful, and appropriate to help establish locations for air sampling, soil sampling, and direct radiation measurements. The importance of evaluating the onsite meteorological conditions as part of the site characterization prior to the onset of preoperational air sampling should be included and emphasized in the revised RG 4.14. Refer to Recommendation 3.1.1.D for an initial discussion of the need for this approach and the recommended time frame to accomplish this objective.

Meteorological data should be collected for at least 12 consecutive months. Upwind and downwind air sampling locations are generally chosen with consideration of wind speeds and direction and other contributing factors, such as topography, atmospheric or barometric pressure, atmospheric stability, rainfall, and temperature (IAEA 2002). Onsite meteorological measurements should be conducted prior to preoperational monitoring activities. These measurements are an important component in the preparation of environmental reports pursuant to 10 CFR Part 51. A monitoring program can be established with the assistance of NRC RG 3.63, *Onsite Meteorological Measurement Program for Uranium Recovery Facilities—Data Acquisition and Reporting* (NRC 1988). In accordance with NRC RG 3.63, the purpose of the onsite meteorological monitoring program is to provide meteorological information necessary to make assessments to aid in demonstrating that the facility design and the conduct of operations are such that releases of radioactive materials to unrestricted areas can be maintained as low as reasonably achievable (ALARA). The meteorological data is used for the design and operation of tailing impoundments and for evaluating the maximum potential annual radiation dose to the public and the environmental impact resulting from the routine release of radioactive materials in gaseous and particulate effluents (NRC 1988). In addition, the meteorological data is used to assess the atmospheric transport of airborne radioactive materials.

The minimum amount of meteorological data necessary for a siting evaluation is considered to be that amount of data collected on a continuous basis for a period of 12 consecutive months that is representative of long-term (e.g., 30 years) meteorological conditions at the site (NRC 1988). The determination of site-specific meteorological conditions has been a topic of discussion among the NRC staff and applicants. Onsite meteorological stations should be deployed to minimize variability often associated with offsite monitoring stations located many miles from the facility. Several variables, such as terrain, the presence of water bodies, and ground cover affect the site's meteorology and are recognized issues at uranium recovery facilities. For example, utilizing meteorological data from an airport located a nominal distance of 50 to 70 miles away from the site is likely not representative of that site. For these reasons, the deployment and collection of onsite meteorological data is recommended. Multiple meteorological stations may also be required to account for varying meteorological conditions such as wind direction.

B. Recommendation: The number of sampling locations in the current guidance (at least three) should be retained and potentially increased based on the evaluation of meteorological data collected prior to the onset of the preoperational phase.

Need to better define this Recommendat

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that the applicants should perform continuous air particulate sampling at a minimum of three locations at or near the site boundary and two additional locations representing one remote, upwind location and one location at the highest predicted concentration to the nearest resident or occupiable structure within 10 km of the site. (For clarification of the site boundary, see Chapter 2 of this TBD.) This guidance was based on one specific type of uranium recovery facility (a conventional mill) with a presumed (or idealized) design based on a central processing facility and continuous surface features. Because this document discusses three types of facilities, the current guidance requires updating to establish the number and locations of air sampling stations.

As discussed in Recommendations 3.1.1.D and 3.1.1.1.A, meteorological data, collected over a period of at least 12 consecutive months, is recommended prior to the onset of the preoperational period. Applicants would use this information to identify both locations and number of air sampling stations. At least three sampling stations would be anticipated at or near the site boundary. For conventional mills and heap leach facilities, the site boundary corresponds to the licensed area controlled by the licensee; air sampling locations should be located at or near this boundary. In the case of ISR facilities, air sampling locations should be placed at or near the boundary of the proposed Central Processing Plant (CPP), satellite facility, and any other facility that handles, stores, or processes large quantities of source materials. Other air sampling locations should be included at or near ISR wellfields and header houses.

The applicants should also take into consideration an onsite annual wind rose evaluation to determine those sectors equal to or greater than 50% of the annual wind rose frequency distribution to place air sampling locations. This approach, as designed, is intended to encourage placement of air sampling stations in the most prevalent wind direction(s). The recommended 50% threshold is based on prior NRC reviews of applicant data representing sectors where three air (particulate) sampling stations were located. The locations of the air sampling stations were then compared to the onsite annual wind rose data. These reviews showed that the sum of the wind rose frequency distribution in the sectors housing the three air sampling stations did not exceed 40% which is deemed inadequate.

To illustrate the use of wind rose frequency distribution, consider the following example:

If the wind rose evaluation showed that four sectors were needed to meet the 50% threshold, then four air sampling stations would be required.

Although the main recommendation is to add more sample locations as needed, there may be a possibility that two sectors meet or exceed the 50% threshold. Therefore, the number of sampling locations may be reduced to two with proper justification and approval from the NRC.

The information that follows is considered supplementary to the primary objective of collecting meteorological data and is offered simply for informational purposes. A non-statistical approach is provided first to support a range of three to eight air sampling locations; a statistical approach is also presented to describe the importance and application of statistical power.

Supplementary Information: Non-statistical Approach (A non-statistical approach is one that may be followed in the absence of or lack of sufficient meteorological data.)

From a non-statistical perspective—that is, strictly from a geometric and visual perspective—the current NRC guidance of three air sampling stations at or near the site boundary would optimally provide 180 degrees of sampling coverage, given that three points form a triangle with maximum angles of 90 degrees (refer to Figure 3-1[a]).

However, expanding to eight sample locations (for example purposes only) could increase coverage to 360 degrees, with eight 45 degree segments (depicted in Figure 3-1[b]). Therefore, the number of sampling locations would effectively form a ring around the site boundary[1]. In the example cited in this section, the ring would be characterized by eight compass directions resulting in a more robust background for future sample comparisons. One measurement would then be taken at each 45 degree "slice of the pie" to ensure coverage in each direction (including downwind locations), rather than sampling points grouped along the prevailing annual or seasonal wind directions (in sectors that have the highest predicted dose to the public or maximum predicted concentrations of radioactive materials).

[1] For ISR facilities, air sampling locations should be placed around the boundary of the proposed CPP, satellite facility and any other facility that handles, stores, or processes large quantities of source materials.

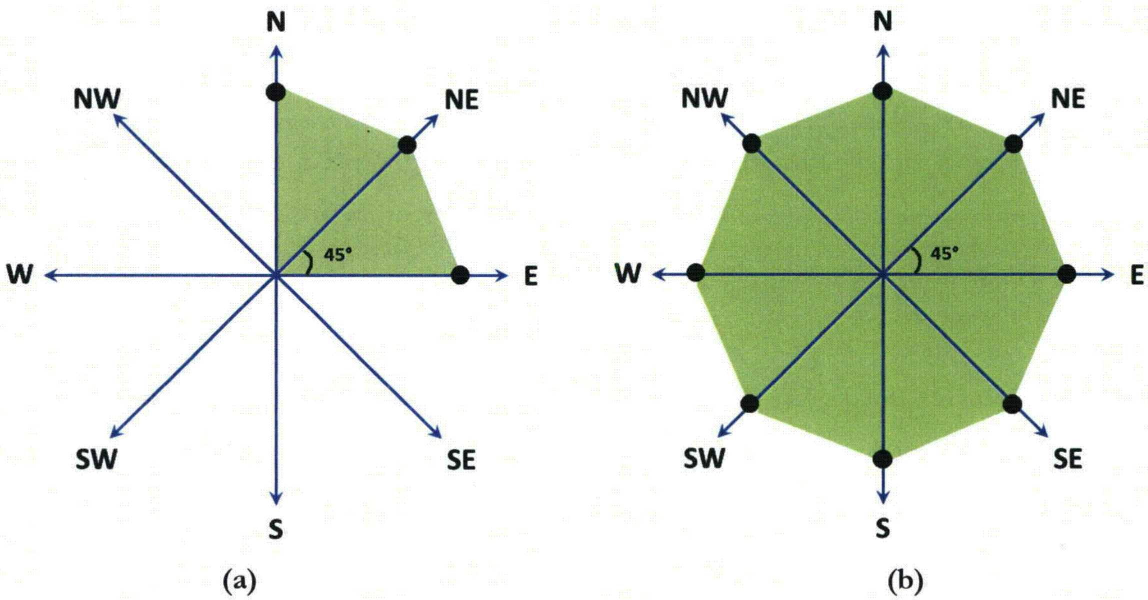


Figure 3-1. Coverage and Angles Associated with (a) Three Sampling Locations and (b) Eight Sampling Locations

At least two additional sampling locations should be included to represent the nearest residence(s) and background/control location(s). Background/control locations are discussed in Recommendations F and G and downwind locations are discussed in Recommendation I.

By determining (and likely increasing) the number of air sampling locations during the preoperational monitoring phase following the acquisition of prior onsite meteorological data, the applicants can account for the spatial and temporal variability in the concentration of air samples and meteorological parameters (e.g., wind direction and wind speed). The data collected from the initial (and presumed increased) number of air sampling locations (relative to the three locations in the current guidance) can provide sufficient information and facilitate the understanding of existing preoperational conditions. The ring of air sampling stations can increase the probability of detection of any particulate and/or radon releases during operations and demonstrate compliance.

Supplementary Information: Statistical Approach (A statistical approach is one that may be used to support the number of sampling locations from a statistical perspective.)

From a statistical standpoint, an increased number of sampling locations (resulting in an equivalent increase in the number of air samples), at a fixed level of confidence, will result in increased statistical "power." Statistical power refers to the probability of rejecting a false null hypothesis and thereby protecting against making Type II decision errors. In other words, it is important to identify statistically significant differences when present.

The Sign Test and the Wilcoxon Rank Sum (WRS) nonparametric test are examples of two statistical tests commonly used for comparing either the mean of one sample to an action level or comparing two different samples. Both tests are described in NUREG-1505 and have been used extensively over the past 15 years to support the data quality assessment phase of the MARSSIM and MARSAME environmental methodologies (NRC 1998a). The Sign Test is used when the contaminant is not present in background (or present at a small fraction of an established action level). The WRS test is used when the contaminant is present in background.

Further discussion using the Sign and WRS tests is provided below. However, the applicant should evaluate whether other statistical tests are more appropriate to determine the number of air sampling stations based on an expected wind rose.

While exact power calculations require an estimate of "effect size," sample size tables for these tests are provided in Tables A.2a (Sign Test) and A.2b (WRS) in MARSAME (NUREG-1575, Supplement 1). The WRS table, replicated below in Table 3-1, is relevant to this discussion as uranium and progeny are present in background at uranium recovery facilities. Effect size is a relative measure of the difference expected based on the standard deviation. (In MARSSIM and MARSAME, the effect size is the "relative shift," Δ/σ, which incorporates the standard deviation into the calculation.) If two samples were being compared, effect size would refer to the magnitude of the difference that would be expected to be statistically significant. The answer depends on the variance (square of the standard deviation) in the sample. Determining the variance requires collecting data and calculating the standard deviation or alternatively, using an estimate of the standard deviation from historical data or another similar population.

If the number of air sampling stations was specifically increased from 3 to 8, an increase in power from 75% to 90% would likely result as described in the example below. The increased power associated with the greater number of air sampling stations would also be reflected in the greater number of collected samples.

Table 3-1 is interpreted as follows. Using the "Scenario A" null hypothesis described in MARSSIM (i.e., the action level is exceeded), the very top row of numbers in the table represent the α (alpha), or confidence level. As an example, an α of 0.05 is equivalent to a 95% confidence level (1-α). The next row is the β (beta), where 1-β represents the power. A beta of 0.10 is equivalent to 90% power. Looking up sample sizes of 3 and 8, respectively, in Table 3-1, a sample size of 3 will provide, at best, an α=0.25 (75% confidence) and β=0.25 (75% power). Alternatively, a sample size of 8 at an α=0.1 (90% confidence) and β=0.1 (90% power) will provide the highest power, as depicted in the table. Specific results would depend on the effect size (the relative shift, Δ/σ) and the specified confidence level. Note also that this example emphasized achieving the highest power.

Table 3-1. Sample Sizes for Wilcoxon Rank Sum Test

(Number of measurements to be performed on the reference material and for each survey unit)

	(α,β) or (β,α)														
	0.01	**0.01**	**0.01**	**0.01**	**0.01**	**0.025**	**0.025**	**0.025**	**0.025**	**0.05**	**0.05**	**0.05**	**0.1**	**0.1**	**0.25**
Δ/σ	**0.01**	**0.025**	**0.05**	**0.1**	**0.25**	**0.025**	**0.05**	**0.1**	**0.25**	**0.05**	**0.1**	**0.25**	**0.1**	**0.25**	**0.25**
0.1	5,452	4,627	3,972	3,278	2,268	3,870	3,273	2,646	1,748	2,726	2,157	1,355	1,655	964	459
0.2	1,370	1,163	998	824	570	973	823	665	440	685	542	341	416	243	116
0.3	614	521	448	370	256	436	369	298	197	307	243	153	187	109	52
0.4	350	297	255	211	146	248	210	170	112	175	139	87	106	62	30
0.5	227	193	166	137	95	162	137	111	73	114	90	57	69	41	20
0.6	161	137	117	97	67	114	97	78	52	81	64	40	49	29	14
0.7	121	103	88	73	51	86	73	59	39	61	48	30	37	22	11
0.8	95	81	69	57	40	68	57	46	31	48	38	24	29	17	8
0.9	77	66	56	47	32	55	46	38	25	39	31	20	24	14	7
1.0	64	55	47	39	27	46	39	32	21	32	26	16	20	12	6
1.1	55	47	40	33	23	39	33	27	18	28	22	14	17	10	5
1.2	48	41	35	29	20	34	29	24	16	24	19	12	15	9	4
1.3	43	36	31	26	18	30	26	21	14	22	17	11	13	8	4
1.4	38	32	28	23	16	27	23	19	13	19	15	10	12	7	4
1.5	35	30	25	21	15	25	21	17	11	18	14	9	11	7	3
1.6	32	27	23	19	14	23	19	16	11	16	13	8	10	6	3
1.7	30	25	22	18	13	21	18	15	10	15	12	8	9	6	3
1.8	28	24	20	17	12	20	17	14	9	14	11	7	9	5	3
1.9	26	22	19	16	11	19	16	13	9	13	11	7	8	5	3
2.0	25	21	18	15	11	18	15	12	8	13	10	7	8	5	3
2.25	22	19	16	14	10	16	14	11	8	11	9	6	7	4	2
2.5	21	18	15	13	9	15	13	10	7	11	9	6	7	4	2
2.75	20	17	15	12	9	14	12	10	7	10	8	5	6	4	2
3.0	19	16	14	12	8	14	12	10	6	10	8	5	6	4	2
3.5	18	16	13	11	8	13	11	9	6	9	8	5	6	4	2
4.0	18	15	13	11	8	13	11	9	6	9	7	5	6	4	2

C. Recommendation: The recommendations in the current guidance for the placement of the upwind (background or control) air sampling location should be retained for conventional mills and heap leach facilities; however, the number of upwind locations should not be limited to one.

Applicability: This recommendation is applicable to conventional mills and heap leach facilities.

Justification/Discussion: At least one background or control air sampling station should continue to be located preferably in the least prevalent wind direction from the site, and unaffected by site operations, uranium mining, or other uranium recovery operations. However, as discussed in prior recommendations, the collection of meteorological data should be the initial primary means used to determine locations and number of air sampling stations. This applies to upwind locations as well. If applicants have more than one control air sampling location, the applicants should use the average of the control sample results.

/ **D. Recommendation:** For ISR facilities, applicants should evaluate whether the upwind (background or control) location(s) should be established at the nearest town or population density center that is beyond the influence of the site, preferably in the least prevalent wind direction.

Applicability: This recommendation is applicable to ISR facilities.

Justification/Discussion: Conventional mills and heap leach facilities have licensed areas that are much smaller than the licensed area at ISR facilities. ISR facilities have potential sources of radiological contaminants distributed in variable locations inside the licensed area. In addition, there are unrestricted areas within the ISR licensed area and situations may exist in which a town or population density center exists near the site.

At least one background or control air sampling station should be located preferably in the least prevalent wind direction unaffected by site operations, uranium mining or other uranium recovery operations. In instances where a town or population density center exists near the site, a background or control location should be located at the nearest town or population density center that is beyond the influence of the site and preferably be in the least prevalent wind direction. Additionally, a town or population density center that is *not* in the least prevalent wind direction is acceptable, but it should be necessary for the applicant to demonstrate that the control location is beyond the influence of the site. A key factor in the location of control air sampling stations is distance from the site. However, current and anticipated changes in land use should also be considered when identifying control or background locations. If applicants have more than one control air sampling location, the applicants should use the average of the control sample results.

ok **E. Recommendation:** The current guidance stating that "...a continuous outdoor air sample should be collected...at or near at least one structure in any area where predicted doses exceed 5 percent of the standards in 40 CFR Part 190" should be eliminated.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Uranium recovery facilities are required to meet the NRC regulations in 10 CFR 20.1301(e) which also require an applicant/licensee to comply with the provisions of 40 CFR Part 190, *Environmental Radiation Protection Standards for Nuclear Power Operations.* 40 CFR 190 is applicable to the radiation doses received by members of the public from the introduction of radioactive materials into the environment as a result of the operations that are part of the nuclear fuel cycle. The regulations in 40 CFR 190.10, *Standards for Normal Operations,* place limits of 0.25 mSv (25 mrem) to the whole body, 0.75 mSv (75 mrem) to the thyroid, and 0.25 mSv (25 mrem) to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, excluding radon and its daughters, to the general environment from uranium fuel cycle operations and of exposures to radiation from these operations.

Air is a primary pathway and must be monitored by the applicants. Currently, no regulatory requirements or technical bases have been identified to support the existing guidance for collecting an outdoor air sample at or near at least one structure in any area where predicted doses exceed 5 % of the standards in 40 CFR Part 190. Air sampling locations should not be tied to a percentage of the Part 190 dose limits.

F. Recommendation: The number of downwind air sampling locations should not be limited to one. (facility) ?

Applicability: This recommendation is applicable to all uranium recovery facilities. In the particular case of ISR facilities, air sampling locations should be downwind of the CPP, satellite facilities, and any other facility that handles, stores, or processes large quantities of source materials.

Justification/Discussion: As described in prior recommendations, the collection of meteorological data over a period of at least 12 months should be used to support the determination of air sampling stations during the preoperational monitoring phase, including downwind locations. The current guidance recommends a single downwind air sampling location during the preoperational phase. However, under the operational phase, the guide recommends "one or more" downwind air sampling location. The recommendations for both phases of monitoring should be revised to specify "at least one" sample for consistency. Air sampling locations should be added as appropriate, particularly in areas that have the highest predicted dose to the public or maximum predicted concentrations of radioactive materials, and at the nearest residence(s) or occupiable structure(s) within the predominant wind direction and located within 10 km of the site boundary. In addition, if the nearest residence or occupiable structure is not located within the predominant wind direction, an air sampling station should be placed at that location.

The applicants should determine if it is necessary or preferable to add, relocate, or eliminate a location; however, approval from the NRC is necessary prior to making modifications in the monitoring program.

A transitional period where co-sampling is conducted should be introduced before permanent modifications in the monitoring program are established. A transitional period of at least one year should be considered. For instance, air sampling locations may be relocated or eliminated if there is no indication that the public or the environment will be affected by site operations at those particular locations.

An exposure pathway analysis can assist the applicants in selecting sampling locations. Because current and anticipated changes in land use near the site should also be considered, a pathway analysis can be also beneficial in evaluating any impacts from these changes.

G. **Recommendation:** Applicants should be provided flexibility in determining the frequency of replacing air filters.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that filters for continuous ambient air samples are normally changed weekly or more often as impacted by dust loading. However, the frequency for changing air filters could potentially be decreased, e.g., to monthly, if air sampling flow rates are not adversely impacted by factors such as the quantity of dust collected on the filter or weather conditions. Applicants should be provided a flexible (graded) approach to determine the frequency of air filter replacement. A technical justification (including air sampling results collected over a specified period) should be submitted to a cognizant regulatory authority to defend the approach.

When conducting air sampling, several factors impact the final determination of activity on the filter and subsequent determination of the concentration in the air. These factors include, but are not limited to, the sampling flow rate, total sampling time, amount of dust (particulates) collected on the filter, and weather conditions impacting the operation of the sampling units (e.g., meteorological conditions and temperature). There are laboratory factors such as the type of counting analysis (e.g., gross alpha versus alpha spectroscopy) that should also be considered.

The type of air sampler employed (e.g., low-volume versus high-volume) has a direct bearing on the activity collected on the filter and concentration in the air. The total volume collected over a specified sampling period will be lower for a low volume sampler with nominal flow rates of a few cubic feet per minute (cfm) relative to a high volume sampler (tens of cfm). For this reason, an air particulate sample, collected on a weekly basis, may or may not be sufficient to satisfy acceptable statistical parameters such as minimum detectable concentrations and measurement uncertainties.

Dust loading also plays a major factor in air sampler performance and the related measurement of the amount of radioactivity present on the filter (particularly if the filter is being counted and analyzed for alpha activity). Significant dust loading is typically manifested by visually observing the sampling flow rate drop and the pump laboring (or beginning to labor) while operating. This situation can occur in one day (or even in as little as one hour or less in the case of surface loading filters such as membrane filters). Modern air samplers are capable of electronically regulating air flow to minimize or eliminate the impact of dust loading (HI-Q 2010). If dust loading is not a factor and weather conditions are not limiting, a longer (e.g., monthly) sampling period is possible. An extended sampling period may in fact be needed at some uranium recovery facilities due to their often remote locations (typically in the western United States) and challenging weather conditions in the winter months. Solar powered (and other powered) air samplers exist and should be considered in these cases.

The additional quantity of radioactivity resulting from the increased volume of air collected may provide more accurate results and reduce the uncertainty in the measurement.

H. Recommendation: The language in Table 1 (*Preoperational Radiological Monitoring Program for Uranium Mills*) of the current guidance should be expanded to match the language in Table 2 (*Operational Radiological Monitoring Program for Uranium Mills*) by including the different sectors having the highest predicted concentrations of airborne particulates.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: In the current guidance, there is a distinction between the location for air particulate sampling in Table 1 and Table 2, respectively. In Table 1, the "Sample Collection" section for air particulates states that samples should be collected at or near the site boundaries. In Table 2, the corresponding section (changes shown in italics) states that samples should be collected at locations at or near the site boundaries *and in different sectors that have the highest predicted concentrations of airborne particulates.* Establishing a strong preoperational air particulate program necessitates the inclusion of sampling locations based on an evaluation of predicted airborne concentrations in wind rose sectors. Adding this recommendation will strengthen the revised regulatory guidance.

I. Recommendation: The preoperational monitoring of radon gas concentrations should be performed in additional locations—beyond those that are co-located with the air particulate sampling stations—for two years.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance recommends that radon (Rn-222) monitoring locations match those established for air particulate monitoring and samples should be collected continuously for at least one week per month. Prior recommendations cited in this document propose that applicants do more preoperational monitoring than what is described in RG 4.14. Included in this recommendation are radon measurements. The rationale for this approach is based on the potential for significant variability in background radon concentrations: that variability should be documented by monitoring for additional time or at additional locations. To help accomplish that objective, meteorological data should be collected for a period of at least 12 consecutive months prior to the preoperational phase to establish air monitoring stations and number of samples. The recommendation to expand this effort is directly related to the importance of radon monitoring. A comprehensive radon assessment provides the applicants (and NRC staff) with information regarding the variability in outdoor radon concentrations surrounding the site and provides the applicants with information to determine those locations in which the highest radon concentrations are expected.

Variability is an important parameter. From a performance-based and risk-informed standpoint, flexibility should be incorporated into the assessment to determine the extent of variability over a specified period; e.g., a year. If after a full year of monitoring (performed following the meteorological monitoring phase), little to no variability in the concentrations of radon gas is identified, additional monitoring locations (more data) may not be necessary.

Determining the control location(s) where radon concentration levels are lowest presents a challenge, since radon concentrations could be higher either upwind or downwind as well as upslope or downslope from terrain influences (NRC 2011e).

In the specific case of ISR facilities, it is anticipated that radon monitoring locations should be placed around the CPP and satellite facilities at identified air particulate monitoring locations. Radon monitoring should not only match the locations of air particulate sampling, but other locations should be added to assess the variability in outdoor radon concentrations.

Additional recommendations regarding measurements of radon and its progeny at uranium recovery facilities are available in the NRC guidance entitled *Evaluations of Uranium Recovery Facility Surveys of Radon and Radon Progeny in Air and Demonstrations of Compliance with 10 CFR 20.1301* (NRC 2011e).

J. Recommendation: Integrating passive devices (e.g., track-etch detectors) should be employed as the method to measure environmental levels of radon in air and deployed at least quarterly.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance recommends that radon should be collected continuously, or for at least one week per month, then analyzed, but it does not provide specific methods for measuring radon in air. The method employed by the uranium recovery facilities involves the use of integrating passive devices (e.g., alpha-track or track-etch detectors) which is acceptable and commonly used to measure environmental levels of radon in air. The deployment of these devices for measuring environmental radon can be from 3–12 months, which is the exposure interval required for these measurements using track-etch detectors (NCRP 1988; George 1996; Maiello and Hoover 2011). Moreover, Maiello and Hoover (2011) indicate that although the mean radon concentration can be estimated from short-term measurements, methods that integrate over a long(er) period of time are preferred since they are more representative of the potential annual dose to humans. During longer monitoring periods (e.g., 6 to 12 months) seasonal variations of the radon concentrations are taken into account in the monitoring as well as any variations (e.g., diurnal, nocturnal) due to highly variable ubiquitous background and equilibrium conditions.

At existing uranium recovery sites, these detectors are usually exchanged quarterly to account for seasonal variation. The length of the deployment or monitoring period has an impact on the minimum detectable concentration (MDC) and the statistical uncertainty of the measurement. For example, current monitoring technology (i.e., track-etch detectors) can achieve theoretical MDCs of 0.1 to 0.3 pCi/L over a 3-month deployment with an approximate uncertainty of 10% (Maiello and Hoover 2011). Alternatively, field MDCs have been estimated to be 0.33 pCi/L based on a 3-month deployment (Landauer 2005). Note that the achievable MDC is equal to or greater than the effluent concentration value of 0.1 pCi/L for radon and its progeny provided in 10 CFR 20, Appendix B, Table 2. A 0.33 pCi/L concentration averaged over a 3-month (90-day) deployment will require a 300-day sampling deployment to achieve an MDC equal to the 10 CFR 20, Appendix B, Table 2 value of 0.1 pCi/L.

The determination of the radon concentration using track-etch detectors depends on the number of tracks per unit area. The uncertainty associated with the radon concentration is inversely proportional to the number of tracks counted (i.e., radon concentration). For example, when a radon concentration equal to or greater than 4 pCi-month/L is monitored during a three month period (or 1.33 pCi/L per month), the uncertainty is approximately 10%, and it decreases as the concentration or sampling period increases (Maiello and Hoover 2011). Assuming a linear response, a radon concentration of 0.33 pCi/L over 3-month deployment will have an uncertainty greater than 10%, but it can be reduced by increasing the sampling period. Moreover, slight increases (or decreases) in the radon concentration close to the achievable MDC (0.33 pCi/L), that would otherwise be masked by the MDC uncertainty, will also be accounted for during longer monitoring periods.

The annual radon concentration can also be estimated using the average concentration associated with shorter monitoring periods (i.e., quarterly). However, when the annual radon concentration and subsequent doses to members of the public are estimated using the average of multiple concentrations, unwanted uncertainties could be introduced into the dose calculation due to uncertainty propagation.

The increased monitoring period will expose the detectors to atmospheric conditions that may cause degradation of the detector's components. Even though environmental interferences are minimal, it is customary to protect the detector from weather conditions using engineered devices to prevent deterioration of the detector's components over time. For example, an alpha-track etch detector can be placed in a vented housing suitable for outdoor deployments. It is not uncommon to place these detectors in a housing co-located at air sampling locations The protective housing will prevent damage due to excessive precipitation. Alpha-track etch detectors can function properly over a wide range of temperatures, up to 160 °F (70 °C) (Landauer 2005). However, prolonged exposures to extreme temperatures—above 122 °F (50 °C)—can cause physical damage to the detector's holder.

Advantages and disadvantages of increasing and decreasing the length of deployment for track-etch radon detectors have been discussed in the previous paragraphs. However, the recommended frequency for uranium recovery facilities to exchange radon detectors is at least quarterly to account for seasonal variation, and for early detection of any potential issues, hence decreasing the current minimum collection frequency from one week to three months.

3.1.1.2. Water Samples

Current Guidance

Section 1.1.2 of the current guidance states the following for the preoperational sampling of water:

> *Samples of ground water should be collected quarterly from at least three sampling wells located hydrologically down gradient from the proposed tailings area, at least three locations near other sides of the tailings area, and one well located hydrologically up gradient from the tailings area (to serve as a background sample). The location of the ground-water sampling wells should be determined by hydrological analysis of the potential movement of seepage from the tailings area, and the basis for choosing these locations should be presented when data is reported. Wells drilled close to the tailings for the specific purpose of obtaining representative samples of ground water that may be affected by the mill tailings are preferable to existing wells.*
>
> *Ground-water samples should also be collected quarterly from each well within two kilometers of the proposed tailings area that is or could be used for drinking water, watering of livestock, or crop irrigation.*
>
> *Samples of surface water should be collected quarterly from each onsite water impoundment (such as a pond or lake) and any offsite water impoundment that may be subject to seepage from tailings, drainage from potentially contaminated areas, or drainage from a tailings impoundment failure.*
>
> *Samples should be collected at least monthly from streams, rivers, any other surface waters or drainage systems crossing the site boundary, and any offsite surface waters that may be subject to drainage from potentially contaminated areas or from a tailings impoundment failure. Any stream beds that are dry part of the year should be sampled when water is flowing. Samples should be collected at the site boundary or at a location immediately downstream of the area of potential influence.*

Recommendations, Applicability, and Justifications/Discussions

The current guidance is limited to monitoring surface and ground water sources at conventional mills. RG 4.14 should be updated to include guidance applicable for heap leach and in situ facilities. Additionally, the updated guidance should include the monitoring of non-radiological (chemical) contaminants for ground water and surface water. The following recommendations, applicability, and justifications are provided to enhance the preoperational water sampling program in RG 4.14.

A. Recommendation: The updated regulatory guidance should include a discussion of ground water sampling frequency.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance recommends that "ground water samples should be collected quarterly" for both monitoring wells and wells that could be used for drinking water, watering of livestock, or crop irrigation. Under the assumption that an adequate number of ground water wells exist at the site, water sampling for all types of facilities should occur at a frequency and to the extent that normal yearly variability, such as natural seasonal variations and human-induced variability due to agricultural pumping, can be established for an area background. Background ground water samples for ISR facilities are needed to establish background conditions in all aquifers and areas that might be affected by excursions outside of the production wellfield, and to establish background or control ground water conditions for all aquifers upgradient of the area of potential influence of the production wellfield. At least eight sets of samples, collected quarterly over the two year preoperational monitoring period to identify seasonal variability, should be analyzed to determine background water quality conditions. Given these factors, a quarterly ground water sampling frequency may still be adequate and guidance should state that samples should be collected at least quarterly. However, an increased sampling frequency (e.g., quarterly to monthly) should be implemented when it is apparent that significant seasonal variation impacts ground water concentrations and data generated from the quarterly sampling results may also not provide sufficient information to attain a complete understanding of normal yearly variability. If temporal variation exists, it may be necessary to sample quarterly for two years to establish the preoperational background.

Applicants should describe the statistical tests employed to develop average ground water results and variability associated with the results. Guidance such as NRC 1981b, ASTM 2005, and EPA 2009 can be used for assistance in determining appropriate statistical methods.

B. Recommendation: Regarding ground water monitoring and sampling, the current guidance should be strengthened for each specific uranium recovery facility type to provide additional information on the ground water monitoring network, including number and locations of ground water wells and depths of monitoring well screens.

Applicability: These recommendations are applicable to all uranium recovery facilities.

Justification/Discussion: The recommendation in the current guidance was written for conventional mills and mill tailings impoundments. It therefore addresses ground water monitoring well locations in relation to a conventional mill tailings impoundment. It states that samples should be collected "from at least three sampling wells located hydrologically down gradient from the proposed tailings area, at least three locations near other sides of the tailings area, and one well located hydrologically up gradient from the tailings area (to serve as a background sample)." The current guidance also recommends that well locations "should be determined by hydrological analysis of the potential movement of seepage from the tailings area, and the basis for choosing these locations should be presented when data is reported. Wells drilled close to the tailings for the specific purpose of obtaining representative samples of ground water that may be affected by the mill tailings are preferable to existing wells."

Ground water monitoring programs should be designed to allow early detection and timely restoration of excursions. General hydrogeological principles indicate that dissolved constituents (contaminants) move with ground water in the direction of ground water flow. Therefore, ground water samples collected from monitoring wells prior to operations will establish the area background ground water quality for comparison during operations so that it can be determined if any degradation of water quality occurs during the operational phase.

With respect to conventional and heap leach facilities, location recommendations in the current guidance for conventional mills are also adequate for heap leach facilities, but the updated guidance needs to reflect that heap leach facilities are being addressed. Monitoring well screening depths should be added to match those depths for conventional mills. Ground water monitoring wells should be screened in the first encountered aquifer since that is the aquifer most likely to experience initial water quality degradation by contaminants leaching into the ground at these facilities. Subsurface hydrogeologic complexity should be taken into account when determining monitoring well placement. Ground water samples from a monitoring well located upgradient provide a record of water quality entering the area that might be affected by uranium milling operations. Ground water samples from monitoring wells located around the periphery (sides) of the proposed tailings area represent water passing through the area that might be affected by uranium milling operations. Ground water samples from monitoring wells located downgradient of the tailings area represent water that has passed beneath the tailings area and will indicate if there is any degradation of ground water quality from uranium mill tailing operations.

The current guidance does not address preoperational background ground water monitoring for ISR uranium recovery facilities. At these types of facilities, the injection and extraction of fluids occurs into and from a specific geologic formation which contains the uranium ore within defined areas in the permit boundary known as wellfields. This injection and production requires pipelines and other infrastructure to carry fluids to and from the wellfields. There may be evaporation ponds or other storage ponds to handle liquid waste fluids. In addition there may be deep disposal wells. Unlike conventional mills, ISR facilities create no mill tailings, so there are no mill tailings impoundments.

Given the specific characteristics of ISR operations the requirements for preoperational ground water monitoring are distinct from conventional and heap leach facilities. As stated in Recommendation A (above), regarding ground water sampling frequency: background ground water samples for ISR facilities are needed to establish background conditions in all aquifers and areas that might be affected by excursions outside of the production wellfield, and to establish background ground water conditions for all aquifers upgradient of the area of potential influence of the production wellfield. Preoperational background should be established as follows:

- At least one upgradient and one downgradient monitoring well should be established in the uppermost, overlying, underlying, and production zone aquifers within a 2 km buffer area of each proposed ISR wellfield.

- At least one monitoring well should be established in each of the following aquifers in the proposed ISR wellfield: uppermost, overlying, underlying, and production zone. The location and number of the wells in the wellfield may be proposed by the applicant as it will be dependent on the proposed wellfield size.

- If any evaporation or storage impoundments will be used, at least one upgradient well and two downgradient wells should be screened within the uppermost aquifer around the impoundment to detect any ground water degradation due to impoundment leakage.

Additional wells may be installed at the applicant's discretion, but given the areal size of ISR license boundaries, it is not required to characterize ground water that has a low likelihood of being impacted by operations.

C. **Recommendation:** The recommendation in the current guidance for the collection of ground water samples from existing private wells within 2 km of tailings areas that are or could be used for drinking water, watering of livestock, or crop irrigation remains adequate for conventional mill facilities and should be extended to ISR and heap leach facilities. Additionally, this distance should be included for the collection of surface water samples from onsite natural and man-made impoundments.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The word "plume" is specifically cited in NUREG/CR-6705 and was retained in this discussion. However, elsewhere in this document the word "excursion" is used.

NUREG/CR-6705 (NRC 2001b) indicates that the average radiological plume dispersion for multiple Uranium Mill Tailings Remedial Action (UMTRA) sites in the United States is less than 2 km for the 10–20 ppb uranium plume contour (including upgradient and downgradient dispersion). The average radiological plume distance was obtained based on averaging the individual maximum axial plume lengths for the UMTRCA Title I and II sites in the United States listed in Table 5 of NUREG/CR-6705. Additionally, NUREG/CR-6705 indicates that the dispersion of non-radiological contaminants mimics that of the radiological contaminants. Non-radiological contaminants have a shorter dispersion range due to the production of relatively insoluble compounds. Therefore, ground water samples collected from private wells located within 2 km of tailings areas and heap leach pads prior to the start of operations will establish the background ground water quality for comparison during operations. It can then be determined if any degradation of water quality occurs during operations of the mill tailings area.

Because the design and layout of heap leach facilities are similar to that found in conventional mills, they are included in this recommendation. In the case of ISR facilities, a radius of 2 km from each proposed ISR wellfield has been found to be sufficient based on historical and current practice. Therefore, the distance of 2 km should also be recommended for ISR facilities unless evidence suggests a larger pumping capture zone of depression is anticipated.

Additionally, the distance of 2 km should also be recommended for the collection of surface water samples from onsite natural and man-made water impoundments that are not associated with proposed site operations. This includes any offsite impoundments that may be subject to seepage from proposed operational areas, direct surface drainage from potentially contaminated areas, or that could be affected by a disposal impoundment failure.

D. Recommendation: The current sampling frequency guidance should be modified to "at least quarterly" and be limited to natural or man-made surface water impoundments.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that "samples of surface water should be collected quarterly from each onsite water impoundment (such as a pond or lake) and any offsite water impoundment that may be subject to seepage from tailings, drainage from potentially contaminated areas, or drainage from a tailings impoundment failure." In the future guidance, a change to "at least quarterly" sampling is recommended. In addition, the sampling frequency is specifically applicable to natural or man-made impoundments (the latter developed by non-applicants/non-licensees not used for the deposition or storage of potential contaminants within 2 km of the site). Impoundments operated by the applicant or licensee where potential contaminants may be deposited do not require surface water sampling.

The objective is to provide sufficient data to capture normal yearly variability. The site's meteorological and hydrogeological conditions may impact the sampling duration. If the sampling is performed at no less than a quarterly frequency, the applicants should perform sampling for two years during the preoperational period.

Surface water can be affected by airborne particulates, overland flow and/or seepage from shallow ground water aquifers into "impounded" surface water bodies; therefore, actual locations to be sampled should be based on careful consideration of the conceptual site model, and in particular, exposure pathways. Sampling locations should include each natural and man-made water impoundment within 2 km of the site that is not associated with proposed site operations. This includes any offsite impoundments that may be subject to seepage from proposed operational areas, direct surface drainage from potentially contaminated areas, or that could be affected by a disposal impoundment failure. If the applicants request sampling of a smaller number of surface water bodies, then justification should be provided to the NRC.

Water sampling should also occur at a frequency and to the extent that normal yearly variation can be established for background "normal" surface water quality. It is important to collect a sufficient number of background surface water samples to establish statistical validity. Applicants should describe the statistical tests employed to cite average surface water results and especially the variability associated with the results. Guidance such as NRC 1981b, ASTM 2005, and EPA 2009 can be used for assistance in determining appropriate statistical methods.

E. **Recommendation:** The current guidance regarding monthly sampling, which includes onsite and offsite collection of samples from streams, rivers, and associated areas, should be retained. However, guidance should clarify the number and location of samples.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that samples from streams, rivers, and other surface waters or drainage systems crossing the site boundary, as well as any offsite surface waters that may be subject to drainage from potentially contaminated areas or from a tailings impoundment failure, should be collected at least monthly. Furthermore, the guidance states that "any stream beds that are dry part of the year should be sampled when water is flowing. Samples should be collected at the site boundary or at a location immediately downstream of the area of potential influence."

With respect to stream beds that are dry or frozen part of the year (ephemeral), it is recommended that during regularly scheduled surface water sampling events, such ephemeral streams are inspected for the presence of flowing water. If flowing water is present, a sample should be taken at that time.

With respect to sample locations for regularly flowing streams, sample locations should be established in the preoperational phase that will also be sampled during the operational phase.

Consistency of sample location is recommended to allow valid comparison of future sample results to the preoperational background. Preoperational sampling should state that samples be collected from at least two separate locations at least monthly from each flowing body of water within the site boundary. Samples should also be collected from any offsite flowing surface water bodies that are sufficiently close to the site to be subject to surface drainage from potentially contaminated areas or that could be influenced by seepage from the following: disposal area(s) (e.g., tailings impoundment failure) or ground water affected by excursions. At least one sample location should be upstream of the site to establish site background or control. A second sample location should be identified downstream of the potential influence to establish a background value for surface water leaving the site to compare with samples collected during the operational phase. (Similar language should be included in the tables for the preoperational and operational monitoring programs; see Recommendation F.)

Monthly sampling is recommended to provide sufficient data for a full understanding of normal yearly variability. The recommendation for monthly sampling may be decreased to quarterly depending on the site's meteorological and hydrogeological conditions. If the sampling is performed quarterly, the applicants should perform sampling for two years during the preoperational period.

Water sampling should occur at a frequency and to the extent that normal yearly variation can be established for background "normal" surface water quality. It is important to collect a sufficient number of background surface water samples to establish statistical validity. Applicants should describe the statistical tests employed to develop average surface water results and describe their understanding of variability associated with the results. Guidance such as NRC 1981b, ASTM 2005, and EPA 2009 can be used for assistance in determining appropriate statistical methods.

F. Recommendation: With respect to flowing surface water bodies, the language in Table 1 (*Preoperational Radiological Monitoring Program for Uranium Mills*) of the current guidance should be expanded to match the language in Table 2 (*Operational Radiological Monitoring Program for Uranium Mills*) by including the establishment of upstream and downstream surface water sampling locations so that consistency is achieved in sample location during the preoperational and operational phases.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: In the current guidance, there is a distinction between the establishment of surface water sampling locations in Table 1 and Table 2, respectively (preoperational and operational monitoring programs). To eliminate any confusion it is recommended that locations for surface water samples should be established in the preoperational phase and for consistency, these same sampling locations should then be used during the operational phase.

Because of the recommendation to sample ephemeral water bodies when water is present, the number of surface water samples from flowing water bodies should be indicated in the tables as "two or more from each body of water."

Inconsistencies in the frequency of sampling of surface water in Table 2 should be corrected. The recommended language to be included in the revised tables is identified in the discussion in Recommendation E.

G. **Recommendation:** Examples of acceptable field sampling methods should be incorporated in the guidance; however, the future RG 4.14 should indicate that the applicant is responsible for choosing, defining, and defending the methods proposed for evaluation to the NRC.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Data results could be questioned unless sampling procedures follow accepted industry standards to ensure defensible data quality. The use of prevailing acceptable standard operating procedures (SOPs) is recommended. The applicants should state which SOPs (or equivalent) they will use or alternatively, develop site-specific protocols and defend the accompanying basis. EPA and ASTM provide standard guides for field sampling activities. These include, but are not limited to: ASTM guides (ASTM 2005, 2006, and 2007), and EPA websites (EPA 2012a, 2012b, and 2012c). These references should be included in the future guidance as examples of standard guides for developing acceptable site-specific field sampling protocols. It is the applicant's responsibility to select, define, and defend the methods proposed to the NRC.

3.1.1.3. Vegetation, Food, and Fish Samples

Current Guidance

Section 1.1.3 of the current guidance states the following for the preoperational sampling of vegetation, food, and fish samples:

> *Forage vegetation should be sampled at least three times during the grazing season in grazing areas in three different sectors having the highest predicted airborne radionuclide concentration due to milling operations.*
>
> *At least three samples should be collected at time of harvest or slaughter or removal of animals from grazing for each type of crop (including vegetable gardens) or livestock raised within three kilometers of the mill site.*
>
> *Fish (if any) samples should be collected semiannually from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by a tailings impoundment failure.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the preoperational sampling of vegetation, food, and fish samples in RG 4.14. Vegetation, food, and fish samples should be collected during the preoperational monitoring phase at the frequency indicated in this section. The sampling method specified in Tables 1 and 2 of the current guidance (i.e., grab sampling), should continue to be recommended in the revised guidance. As described in Chapter 4, Land Use Census, of this TBD, the specific type of vegetation or livestock samples should be specified by using the common names. For example, a common name for a plant is "big sagebrush" and a common name for livestock is "cattle." The scientific name (genus/species) may be provided if it is readily available. Generic terms such as vegetation, plant, crops, or livestock should be avoided. This approach also applies to fish.

A. Recommendation: The current guidance to obtain forage vegetation samples at the specified locations and frequency should be retained.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Radiological contaminants are predominantly dispersed via air and water sources. As described in several references, airborne contaminants are directly deposited onto nearby vegetation and surface soils (e.g., Carvalho et al. 2007), while those dispersed via water transport are commonly absorbed in nearby soils and subsequently absorbed by vegetation. Therefore, sampling of vegetation should be performed at the locations where the distributions of contaminants (via water and air) are expected to yield the highest concentration. Additional sampling locations may be warranted based on the site-specific characteristics and conditions.

Additionally, forage vegetation (including wetland plants) may be the principal food source for grazing and game animals. Therefore, due to the risk of ingestion of contaminated dairy and meat products by members of the public, forage vegetation should be collected during grazing periods. The collection of multiple vegetation samples during the grazing season may provide an assessment of possible build-up of contaminants in grazing areas and retention fraction of contaminants in grazed animals.

B. Recommendation: The current guidance to obtain crop samples (including those from vegetable gardens) or livestock samples at the specified locations and frequency should be updated to include the option to obtain samples of game animals.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Human consumption of livestock, game, and garden vegetables provides an indirect pathway for the intake of radiological contaminants. Edible portions of meat from livestock and game, as well as garden vegetables, should be analyzed to assess the migration of contaminants in the food chain, and potential ingestion by members of the public.

The current guide specifies that: "At least three samples should be collected at time of harvest or slaughter or removal of animals from grazing for each type of crop (including vegetable gardens) or livestock raised within three kilometers of the mill site." This should be interpreted in the revised guide as one sample from each of three different livestock animals—e.g., cattle, sheep (if available)—used for human consumption within 3 km of the site boundary[2]. Alternatives to livestock are game and crops. Game animals should be included in the future guide, since hunting may be significant in areas where uranium recovery sites are typically located. Although sampling of meat animals is optional, it may be necessary for the applicant to obtain preoperational data. If there is no preoperational data available and sampling of livestock or game is conducted during the operational monitoring, then a comparison cannot be established.

C. Recommendation: The current guidance to obtain fish samples at the specified locations and frequency should be retained.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Fish and other aquatic biota may populate bodies of water within and beyond the proposed site boundary. The distribution of soluble contaminants in rivers and streams can extend for several kilometers (Muscatello and Janz 2009; Peterson et al. 2002; Havlik et al. 1968a and 1968b). On the other hand, insoluble compounds have limited distribution ranges (NRC 2001b) and may accumulate in locations where the flow of water is limited or precipitates to the bottom sediment (Winde 2002). Additionally, the distribution of contaminants in streams and rivers is downstream (Peterson et al. 2002).

Bodies of water located near or within the proposed boundary of uranium recovery facilities may contain sufficient nutrients to support fish populations and other aquatic biota adequate for seasonal game fishing and, thus, consumption. As is the case for livestock, game, and garden vegetables, consumption of contaminated fish is an indirect pathway for the intake of radiological contaminants.

[2] For ISR facilities the samples should be collected within 3 km of the boundary of the proposed CPP, satellite facility, or any other facility that handles, stores, or processes large quantities of source materials.

3.1.1.4. Soil Samples

Current Guidance

Section 1.1.4 of the current guidance states the following for the preoperational sampling of soil:

> *Prior to initiation of mill construction (and if possible prior to mining), one set of soil samples should be collected as follows:*
>
> *a. Surface-soil samples (to a depth of five centimeters) should be collected using a consistent technique at 300 meter intervals in each of the eight compass directions out to a distance of 1500 meters from the center of the milling area. The center is defined as the point midway between the proposed mill and the tailings area.*
>
> *b. Surface-soil samples should also be collected at each of the locations chosen for air particulate samples.*
>
> *c. Subsurface samples (to a depth of 1 meter) should be collected at the center of the milling area and at a distance of 750 meters in each of the four compass directions.*
>
> *Soil sampling should be repeated for each location disturbed by site excavation, leveling, or contouring.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the preoperational soil sampling program in RG 4.14. Soil and sediment can be impacted in different ways. Soils may be operationally impacted from stack release and windblown air depositions, spills, water runoff and deposition, and similar pathways. Sediments would be expected to be primarily impacted from water runoff or discharge point sources. For this reason, separate discussions of these two media are presented in this document in contrast to the current RG 4.14.

Soil samples should be collected once, prior to site construction during the preoperational monitoring phase. Soil sampling should be repeated for each location disturbed by site excavation, leveling and contouring. The objective remains to establish an appropriate background for future use in comparison with routine environmental monitoring data to evaluate potential trends or impacts during the operational period and for use in future decommissioning activities.

A. Recommendation: The current guidance for preoperational soil sampling locations should be evaluated on a facility-specific basis.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: An acceptable preoperational soil sampling program should provide sufficient information to assess the existing soil conditions as well as to provide adequate information to support future radiological assessments. The current guidance describes soil sampling locations for conventional mills. The guidance should be strengthened by recommending that applicants evaluate soil sampling locations on a facility-specific basis. (Refer to Recommendation B for additional supporting information.) Additionally, appropriate field sampling methods should be determined and documented by the applicants in facility procedures and protocols. The recommendation in the existing guidance to use grab methods for soil sampling is inadequate, since specific guidance, e.g., depth is being provided. Grab sampling methods are adequate for other media such as vegetation and sediment discussed in this TBD.

The current guidance recommends a radial sampling plan with the origin at the mid-point between the proposed mill site and tailings area. The radial grid may have been adopted from RG 4.5, issued in 1974. As illustrated in Figure 3-2, this sampling pattern results in a much greater sample density in the center versus the radii and therefore may potentially skew the preoperational conclusions because of unintended data weighting factors that would result. If the preoperational parameters of interest were known to be homogenously distributed over the sampled area, and if potential future trends in site conditions were expected to exhibit stratified deposition, which may or may not be the case for various facility types and environmental impact pathways, then the current sample location guidance might be acceptable.

However, the type of sample plan implemented should be based on knowledge of the parameter(s) of interest distribution and on the data end use. Historically, for example, establishing the background distributions of Ra-226 in soil at uranium mills has shown extensive variability due to the local geology. Data end-use factors to consider in planning include estimating the mean, variability, or percentiles of a parameter of interest; developing confidence intervals; and other statistical inferences. Additionally, the data could be expected to be used in identifying spatial patterns in background conditions and later combined with environmental monitoring data for trend analyses and/or a localized data point impulse (e.g., a spill or unexpected release of radioactive materials) identification.

A square or triangular random-start/systematic or systematic Cartesian grid-based sample plan should be used for all facilities instead of the radial grid; this optimizes data end-use and site information, and eliminates an NRC-recommended sampling distance. As illustrated in Figure 3-3, this type of sampling plan provides more representative spatial coverage and therefore distribution information and background conditions; avoids unintentionally weighting the results obtained from locations near the center of the radial pattern as each location is independent and represents an equivalent area; and increases the probability of detecting trends or outliers in the future. Selection of square or triangular sample patterns and whether a random-start point is selected (versus an applicant-defined start point—such as a property corner) should be determined on a site-specific basis. In general, selecting a random start point eliminates real or perceived bias in sample location selection and is therefore recommended as the default approach. Random-start/systematic sampling locations are easily generated using software (e.g., Visual Sample Plan) or by otherwise generating random numbers—common methods include look-up tables provided in many statistics textbooks, desktop software, and scientific calculators—to decide start point and sample spacing, as described in EPA 2002a. Whether the applicant chooses the square or triangular pattern should also be a site-specific determination. However, using the triangular pattern improves the probability of identifying localized variability.

All types of uranium recovery facilities applicants should collect soil samples from Cartesian grid-based locations during one sampling event, prior to site construction, as recommended in the current guidance. It is further recommended that up to 40 soil samples be collected as follows: surface soil samples (defined as the 0 to 15 cm interval) are collected from up to 35 locations and up to 5 of those locations are sampled such that the surface soil samples are collected followed by subsurface soil samples to a 1 m depth. The 5 subsurface locations would include the center-most of the preoperational sampling area, and the other four subsurface samples would be collected from the locations that most closely represent the point equidistance between the center and four corners of the sampling area. Furthermore, after the site has been prepared for construction, surface soil sampling should be repeated at each original soil sample location disturbed by site excavation, leveling, or contouring to determine whether initial soil conditions were altered during site preparation activities. Radiological conditions measured after site preparation activities should be recorded as the new background data for the specific area(s).

The current practice of collecting surface soil samples—to a 5 cm depth—at all air particulate monitoring stations should be continued. The surface soil samples at the air monitoring stations should be collected once prior to site construction.

For conventional mills and heap leach facilities, the (up to) 40 soil samples should be distributed within the site boundary, as shown in Figure 3-3. (For clarification of the site boundary for conventional mills and heap leach facilities, see Chapter 2 of this TBD.)

For ISR facilities, up to 40 soil samples should be distributed within the boundary of the proposed CPP, satellite facility, and any other facility that handles, stores, or processes large quantities of source materials. The distribution of sample locations to each facility will be weighted based on the area of the facility (i.e., more samples should be collected from larger facilities). To determine weighted sample location distribution, the total area covered by proposed facilities should be calculated. Then divide each individual facility area by the total area and multiply the result by the total number of surface soil samples as well as (separately) by the total number of subsurface soil samples to get the respective numbers of samples for that facility. The (up to 40) soil samples should be collected once prior to site construction.

As a hypothetical example, if an ISR facility's CPP has an area of 75,000 m^2 and has two satellite facilities (Facilities A and B) that have areas of 25,000 m^2 and 15,000 m^2, the applicant would collect 26 soil samples from the CPP, and 9 and 5 samples from the satellites, respectively, to reach a total of 40. This example is expressed numerically as:

75,000 + 25,000 + 15,000 = 115,000

75,000 / 115,000 = 0.65

0.65 × 35 = 23 (The CPP will have 23 surface soil samples.)
0.65 × 5 = 3 (The CPP will have 3 subsurface soil samples.)

25,000 / 115,000 = 0.22
0.22 × 35 = 8 (Satellite Facility A will have 8 surface soil samples.)

$0.22 \times 5 = 1$ (Satellite Facility A will have 1 subsurface soil sample.)

$15{,}000 / 115{,}000 = 0.13$
$0.13 \times 35 = 4$ (Satellite Facility B will have 4 surface soil samples.)
$0.13 \times 5 = 1$ (Satellite Facility B will have 1 subsurface soil sample.)

For ISR facilities, soil sampling should be repeated at each original soil sample location disturbed by site excavation, leveling, or contouring of proposed CPP (and any other facility that handles, stores, or processes large quantities of source materials), as well as any proposed satellite facility footprint to determine whether soil initial radiological conditions were altered during site preparation activities. Radiological conditions measured after site preparation activities should be recorded as the new background data for the specific area(s).

In addition to sample collection, preoperational gamma radiation scans should be conducted once prior to site construction along the grid transects within the boundary of, for example, the CPP at ISR facilities. (Preoperational gamma soil scanning is not being recommended for conventional mills or heap leach facilities, although performing these scans for all types of facilities is encouraged.) The applicant should define the necessary density of scanning transects, with the minimum recommended coverage equating to each X,Y transects as shown in Figure 3-4. The use of global positioning systems (GPS)-enabled data loggers would permit the applicant to map the data to illustrate the background gamma radiation levels for the preoperational site. Judgmental (biased) samples taken at any anomalous locations identified during the preoperational gamma scans are also recommended.

Applicants should determine the scanning techniques and the equipment to be used. This information should be provided to the NRC. (Refer to Recommendation A of Section 3.1.1.6 for information pertaining to gamma radiation scanning methods and techniques.)

After ISR facilities have been prepared for construction, soil scanning should be repeated along the grid transects disturbed by site excavation, leveling, or contouring of the proposed CPP (and any other facility that handles, stores, or processes large quantities of source materials), as well as any proposed satellite facility footprint to determine whether initial radiological conditions were altered during site preparation activities. Radiological conditions measured after site preparation activities should be recorded as the new background data for the specific area(s).

The collection of soil samples can also be tied to direct radiation measurements, where it is possible (though not certain) that concentrations of radiological contaminants in soil (becquerels/kg or pCi/g) can be correlated with field measurements recorded in count rates (cpm) or preferably in exposure rates (μR/hr) or dose rates (μrem/hr) at identified locations. This practice is not uncommon and is not discouraged; it should be recognized, however, that strong correlations may not (and often do not) exist due to the radiation emissions associated with uranium series radionuclides, soil attenuation effects, and other factors encountered under field measurement conditions.

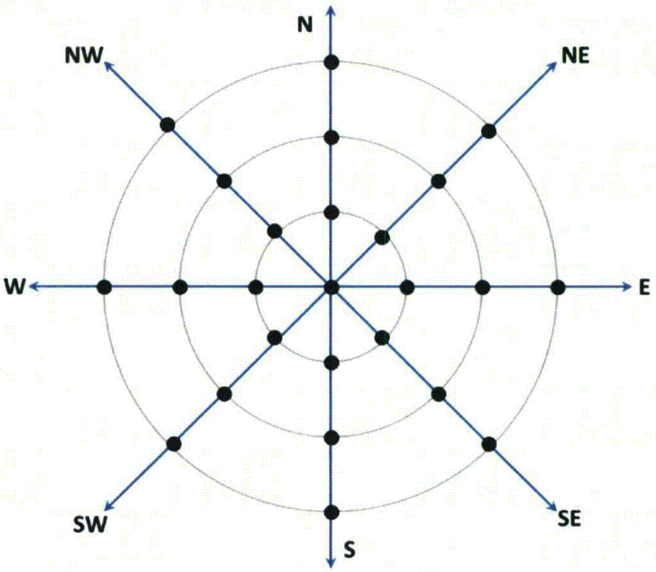


Figure 3-2. Example of Radial Grid in the Current RG 4.14*

*This figure does not illustrate the exact number of currently recommended samples.

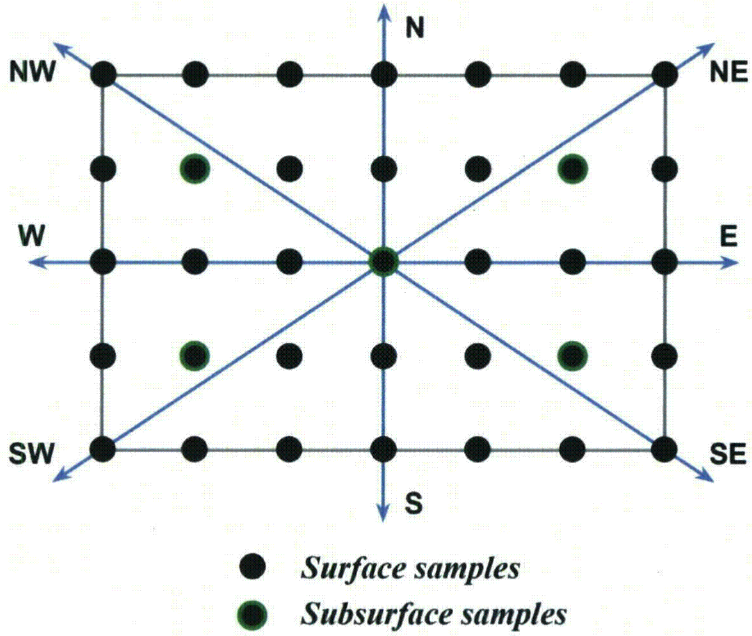


Figure 3-3. Recommended Cartesian Grid with Sample Locations

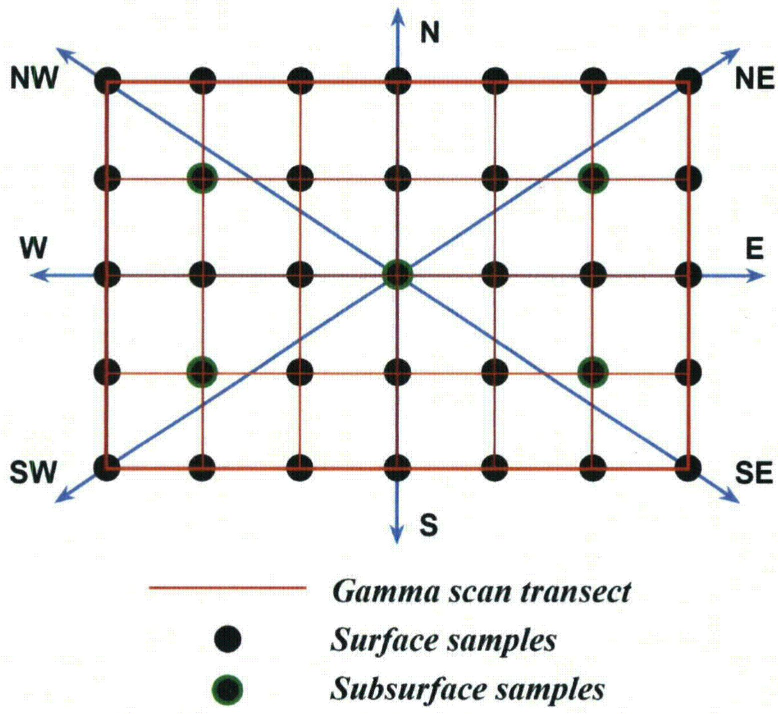


Figure 3-4. Recommended Cartesian Grid with Sample Locations and Gamma Scan Transects

B. Recommendation: Surface soil sampling depths collected during the preoperational sampling period should be expanded in the revised guidance to include a 15 cm depth consistent with 10 CFR Part 40, Appendix A.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance in RG 4.14 (Section 1.1.4, *Soil and Sediment Samples*) states that surface soil samples should be collected to a depth of 5 cm (2 in). No other sampling depths are recommended. Multiple regulatory and guidance documents, however, cite alternative surface sampling depths. 10 CFR 40, Appendix A, Criterion 6, requires the assessment of surface soil contamination (specifically Ra-226 and Ra-228) averaged over the first 15 cm (6 in) below the surface. 10 CFR 40 references 40 CFR 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings and Uranium In Situ Leaching Processing Facilities*, where the 15 cm collection depth is described in the context of uranium ore processing and disposal of waste materials. While the revision of RG 4.14 is not intended to address decommissioning, the 15 cm depth would be applicable to future decommissioning activities, indicating that preoperational sampling to this depth is advantageous for comparative purposes.

Available characterization and decommissioning guidance in NUREG-1757, Volume 2 (NRC 2006) and MARSSIM (NRC 2000), respectively, defines surface soil as the uppermost soil to a depth of 15 cm. MARSSIM, Section 4.7.3, *Criteria for Selection of Sample Collection and Direct Measurement Methods*, references the RESRAD Manual (Yu et al. 2001) and NUREG/CR-5512, Volume 2, *Residual Radioactive Contamination From Decommissioning* (NRC 2001c), to describe a rationale for this depth, i.e., it is a depth that could be appropriate for a final status survey as it "corresponds to the soil mixing or plow depth in several environmental pathway models." Acceptable surface soils screening values, utilized to demonstrate compliance with the release criteria for license termination, are also based on soil contamination to a depth of 15 cm (NRC 2006).

Sampling depth is affected by several factors, including the type of scenario (e.g., agricultural, ranching, or recreational), radionuclides of concern, the deposition pathway, and satisfying MDC requirements when analyzing the samples. The type of scenario, whether agricultural or otherwise, incorporates into the dose an individual will receive a variety of factors, including pathway analyses, time spent onsite, and planned activities. The dose can be related back to applicable soil criteria, and in turn, an appropriate sampling depth to meet those criteria. In an agricultural scenario, for example, the sampling depth is based on the assumption that the top few centimeters of soils are homogenized. An identical or different sampling depth may apply to ranching, recreational, and other scenarios.

The deposition pathway and solubility of the element of interest should be considered in the justification of a surface sampling depth. For instance, when airborne deposition is the primary contaminating pathway, a shallow surface sample (to a 5 cm depth) is currently recommended by the NRC at air sampling stations. Regarding solubility, radionuclides associated with the uranium series and recovery operations, e.g., Ra-226, could migrate to a greater depth in soil. In this situation, sampling to a greater (e.g., 15 cm) depth would be more appropriate and is also recommended by the NRC.

In summary, in the revised RG 4.14, it is recommended that surface soil samples collected during the preoperational program at environmental air sampling stations be collected to a depth of 5 cm. At all other locations, surface soil samples should be collected to a depth of 15 cm consistent with 10 CFR Part 40, Appendix A (and 40 CFR 192) to satisfy the radium benchmark criterion.

3.1.1.5. Sediment Samples

Current Guidance

Section 1.1.4 of the current guidance states the following for the preoperational monitoring of sediment samples:

> *One set of sediment samples should be collected from the same surface-water locations as described in Section 1.1.2. For surface water passing through the site, sediment should be sampled upstream and downstream of the site. Samples should be collected following spring runoff and in late summer, preferably following an extended period of low flow. In each location, several sediment samples should be collected in a traverse across the body of water and composited for analysis.*

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the preoperational sediment sampling program in RG 4.14. Sediment samples should be collected once during the preoperational monitoring phase as indicated in this section.

A. **Recommendation:** The current guidance to collect sediment samples at specified locations and frequency should be retained.

   Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

   Justification/Discussion: The current guidance describes sediment sampling locations and the frequency of collection in general terms. The guidance is adequate and no significant modifications are needed in the revised RG 4.14. Applicants should collect samples using grab sampling methods or may document appropriate alternate field sampling methods in facility procedures and protocols. Applicants would be expected to determine the sediment sampling locations and collection frequencies on a facility-specific basis.

3.1.1.6. Direct Radiation

Current Guidance

Section 1.1.5 of the current guidance states the following for preoperational direct radiation measurements:

> *Prior to initiation of mill construction (and if possible prior to mining), gamma exposure rate measurements should be made at 150-meter intervals in each of the eight compass directions out to a distance of 1500 meters from the center of the milling area. Measurements should also be made at the sites chosen for air particulate samples.*
>
> *Measurements should be repeated for each location disturbed by site excavation, leveling, or contouring.*
>
> *Gamma exposure measurements should be made with passive integrating devices (such as thermoluminescent dosimeters), pressurized ionization chambers, or properly calibrated portable survey instruments.*
>
> *Direct radiation measurements should be made in dry weather, not during periods following rainfall or when soil is abnormally wet.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the conduct of preoperational direct radiation measurements described in RG 4.14. Direct radiation measurements should be taken during the preoperational monitoring phase.

A. Recommendation: Applicants are encouraged to make use of currently available or newer techniques to perform direct radiation measurements.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Given a proposed facility design and layout, the preoperational monitoring program for direct radiation measurements at uranium recovery facilities should generate sufficient initial data to characterize the existing background radiological conditions in support of the potential sources of radioactivity that will appear during the operational phase.

Direct gamma radiation measurements can be accomplished in several ways, including passive methods, direct measurements, and scanning methods.

Passive measurements include the placement of thermoluminescent dosimeters (TLDs) or optically stimulated luminescent (OSL) dosimeters at designated fixed locations for an extended period of time (normally for periods of three months), and then processed to determine dose. Additionally, gamma exposure rate measurements can also be taken at fixed locations using instrumentation such as pressurized ionization chambers (PIC) or other instrumentation such as microroentgen or microrem meters that directly read out in μR/hr or μrem/hr, respectively. These devices contain a pressurized gas, PIC, or a sodium iodide or plastic scintillation detector inside the casing. Measurements are often taken at a nominal 1 m distance from the surface (essentially representing a generic dose). Many of these devices employ (or can be modified to employ) data logging techniques to accumulate and electronically record a significant quantity of data (thousands of data points) that can be downloaded in real time. Microrem meters containing plastic scintillators are known for a flat energy independent response, a benefit in dose conversions and comparison to worker and public regulatory limits. In contrast to TLDs and OSLs, gamma exposure rate measurements using hand-held instrumentation are real-time instantaneous measurements that represent the radiological conditions at the time of measurement only (not integrated over a period of time).

Passive integrating dosimeters, such as TLDs, are commonly used as a detection mechanism for low-level environmental gamma radiation measurements. These dosimeters have historically been the preferred detection mechanism for low-level radiation measurements (NCRP 1976; IAEA 2002). TLDs placed in a field setting are compared to control dosimeters to estimate the integrated (total) dose over the deployment period. More recently, OSLs are being used, due to their response to a wide range of gamma energies, to monitor gamma exposures in the environs. OSLs have an advantage of lower detection limits (as low as 0.1 mrem) and the ability to be read at any time during the period to determine accumulated dose without affecting the dosimeter's ability to continue to accumulate dose. Furthermore, their rugged construction ensures that the dosimeters can withstand variations in environmental conditions without compromising the recorded dose (NCRP 1976). Calibrated portable instruments could also be utilized for single-point measurements. However, in the case of direct read-out portable instruments, multiple measurements (e.g., ten measurements) per location should be collected and subsequently averaged to minimize potential human errors and fluctuations in the sample distribution. Portable instruments are available that are capable of integrating the exposure/dose rate over a selected time-period (one-minute count or longer) then reporting the average observed measurement.

Passive integrating devices are useful for environmental exposure rate applications. Their deployment period can be shortened or extended to account for seasonal variations or fluctuations in the sample distributions that would affect the exposure rate at the location of interest.

Although the current guidance does not specify an exchange frequency for passive monitoring during the preoperational phase, it is recommended that quarterly exchanges be performed. This aligns with the current guidance for the operational phase. Applicants should provide a justification to the NRC for modifying the passive monitoring period when quarterly exchanges of passive devices are not performed.

Another approach to measuring direct radiation is through scanning. Scanning methods are accomplished by transporting an instrument from location to location (i.e., walkovers surveys). Historically, sodium iodide (NaI) scintillation, and more recently large-area plastic scintillator, detectors, have been routinely used for gamma measurements during walkover surface scans of open land areas. In these cases, the detector is physically located separately from the readout device (attached by an electronic cable) and is moved over the ground surface at a specified height and speed. Typically, the output reading is in counts or thousands of counts per minute. Conversion to exposure rate or dose rate is possible through cross-calibration methods (e.g., comparing the count rate to the exposure rate or dose rate, plotting the data, and developing a response curve).

The current RG 4.14 has limitations because computer codes and other technical advances were not available in 1980. Applicants can now utilize GPS paired with portable instrumentation to perform walkover or vehicle scanning measurements of the proposed uranium recovery site and establish background radiological conditions and identify areas of elevated radioactivity. The results of the preoperational scans may then be used for comparison with operational and post-operational survey results to determine any potential changes.

The use of mobile vehicles for conducting gamma radiation measurements over very large land areas, with the capability of real time results, has increased significantly over the past several years. "Mobile" is defined here as any vehicle that moves and carries radiation detectors affixed to the vehicle. Uranium recovery facilities and adjoining areas are conducive to this approach; a primary advantage is the collection of much more data over a very large area and in less time relative to other methodologies (such as fixed measurements) or conventional walkover gamma survey scans.

As with any of the applications described here, there are advantages, disadvantages, and technical considerations applicants should consider and describe in their planning documents. These considerations include equipment and labor costs, detector sensitivity, and statistical considerations. For example, sodium iodide detectors are relatively inexpensive (though that changes quickly with increasing size of the crystal), but quite fragile and temperature sensitive. Traversing many acres on foot to acquire the necessary radiation data will require a significant time commitment at uranium recovery facilities. A mobile vehicle would typically be equipped with multiple radiation detectors (ordinarily sodium iodide or plastic scintillators). Statistical considerations are important as land areas must be traversed at a rate of speed sufficient to meet detection sensitivity requirements. For example, traveling too fast in these vehicles or with the detector too high above the ground surface are known issues as the detector's observation time will decrease with increasing scan speed and sensitivity decreases with increasing height. Another area needing careful consideration is the conversion of the instrument response (typically expressed in counts) into a data format that can be used for direct comparison with regulatory parameters (i.e., exposure rates or a concentration). Establishing these correlations may be influenced by the radiation emissions associated with uranium series radionuclides, soil attenuation effects, and other factors encountered under field measurement conditions. Determining what radionuclides are contributing to the recorded instrument response and their contributing fractions are related issues. However, an investigation level may be established to determine if further analysis—e.g., radiological laboratory analysis—is needed.

B. Recommendation: The current guidance for performing direct radiation measurements should be evaluated on a facility-specific basis.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: An acceptable preoperational direct radiation measurement program should provide sufficient information to assess the existing gamma exposure rates as well as to provide adequate information to support future radiological assessments. The current guidance uses a radial grid to determine direct radiation measurement locations. It is recommended that the radial grid and associated distances be eliminated—based on information presented in Recommendation A of Section 3.1.1.4—and a Cartesian grid be used instead. A square or triangular random-start/systematic or systematic Cartesian grid-based sample plan should be used for all facilities instead of the radial grid; this optimizes data end-use and site information, and eliminates an NRC-recommended sampling distance. This type of sampling plan provides more representative spatial coverage and therefore distribution information and background conditions; avoids unintentionally weighting the results obtained from locations near the center of the radial pattern as each location is independent and represents an equivalent area; and increases the probability of detecting trends or outliers in the future. Selection of square or triangular sample patterns and whether a random-start point is selected (versus an applicant-defined start point—such as a property corner) should be determined on a site-specific basis. In general, selecting a random start point eliminates real or perceived bias in sample location selection and is therefore recommended as the default approach. Random-start/systematic sampling locations are easily generated using software (e.g., Visual Sample Plan) or by generating random numbers to decide start point and sample spacing, as described in EPA 2002a. Whether the applicant chooses the square or triangular pattern should also be a site-specific determination. However, using the triangular pattern improves the probability of identifying localized variability.

Conventional mill/heap leach applicants should continue to perform these measurements at up to 80 locations once prior to site construction, as recommended in the current guidance. However, these measurement locations should be determined using the Cartesian grid during preoperational direct radiation measuring efforts. The (up to) 80 separate measurement locations should be distributed within the site boundary, as shown in Figure 3-5. (For clarification of the site boundary for conventional mills and heap leach facilities, see Chapter 2 of this TBD.) After conventional mill/heap leach facilities have been prepared for construction, direct radiation measurements should be repeated at each original measurement location disturbed by site excavation, leveling or contouring to determine whether radiological conditions were altered during site preparation activities.

If the conventional mill/heap leach applicant decides to perform gamma radiation scans along the Cartesian grid transects within the site boundary, rather than taking measurements at (up to) 80 separate locations, the applicant should define the necessary density of scanning transects with the minimum recommended coverage equating to each X,Y row as shown in Figure 3-6. The use of GPS-enabled data loggers would permit the applicant to map the data to illustrate the background gamma radiation levels for the preoperational site. After conventional mill/heap leach facilities have been prepared for construction, direct radiation measurements should be repeated along the grid transects disturbed by site excavation, leveling, or contouring to determine whether radiological conditions were altered during site preparation activities.

Radiological conditions measured after site preparation activities should be recorded as the new background data for the specific area(s).

For ISR facilities, preoperational gamma radiation scans should be conducted once prior to site construction along the grid transects within the boundary of the proposed CPP, satellite facility, and any other facility that handles, stores, or processes large quantities of source materials. The applicant should define the necessary density of scanning transects, with the minimum recommended coverage equating to each X,Y transect as shown in Figure 3-6. The use of GPS-enabled data loggers would permit the applicant to map the data to illustrate the background gamma radiation levels for the preoperational site. After ISR facilities have been prepared for construction, direct radiation measurements should be repeated along the grid transects disturbed by site excavation, leveling, or contouring of the proposed CPP (and any other facility that handles, stores, or processes large quantities of source materials), as well as the proposed satellite facility footprint to determine whether radiological conditions were altered during site preparation activities. Radiological conditions measured after site preparation activities should be recorded as the new background data for the specific area(s).

Additionally, for all uranium recover facilities, the current practice of taking direct radiation measurements once prior to site construction at all air particulate monitoring stations, as specified in the current guidance, should be continued. Direct radiation measurement method should be determined by the applicant.

Applicants should determine the scanning techniques and the equipment to be used. This information should be provided to the NRC. (Refer to Recommendation A of Section 3.1.1.6 for information pertaining to gamma radiation scanning methods and techniques.)

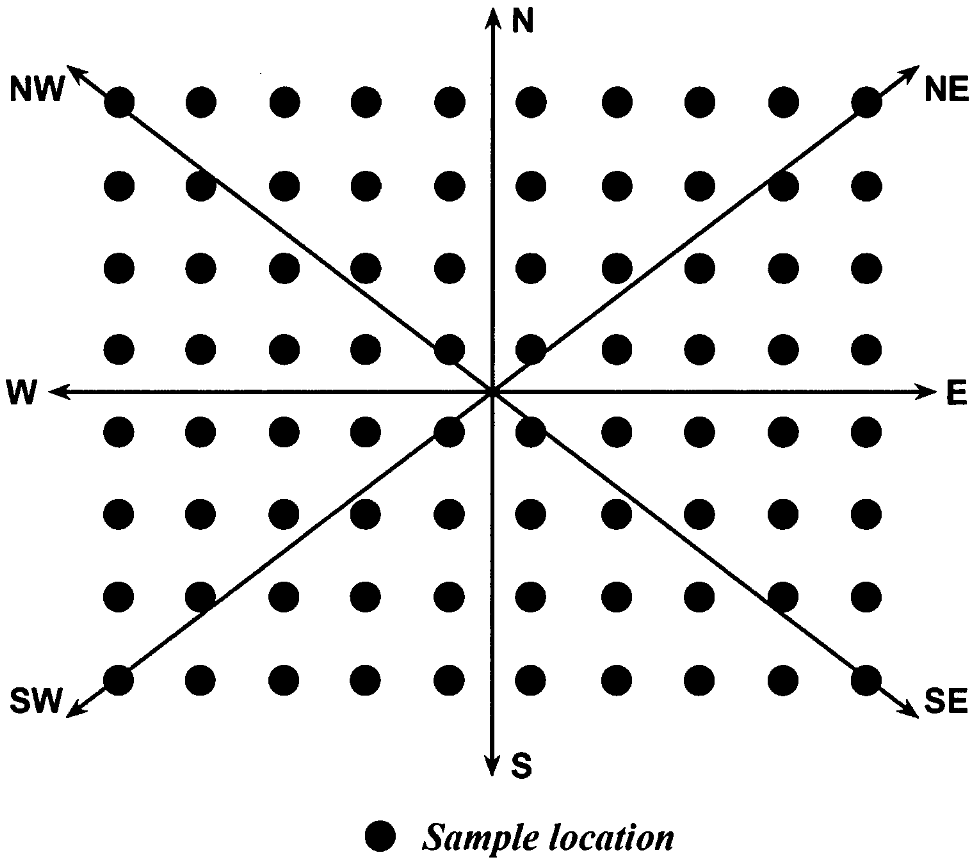


Figure 3-5. Recommended Cartesian Grid with Direct Radiation Measurement Locations

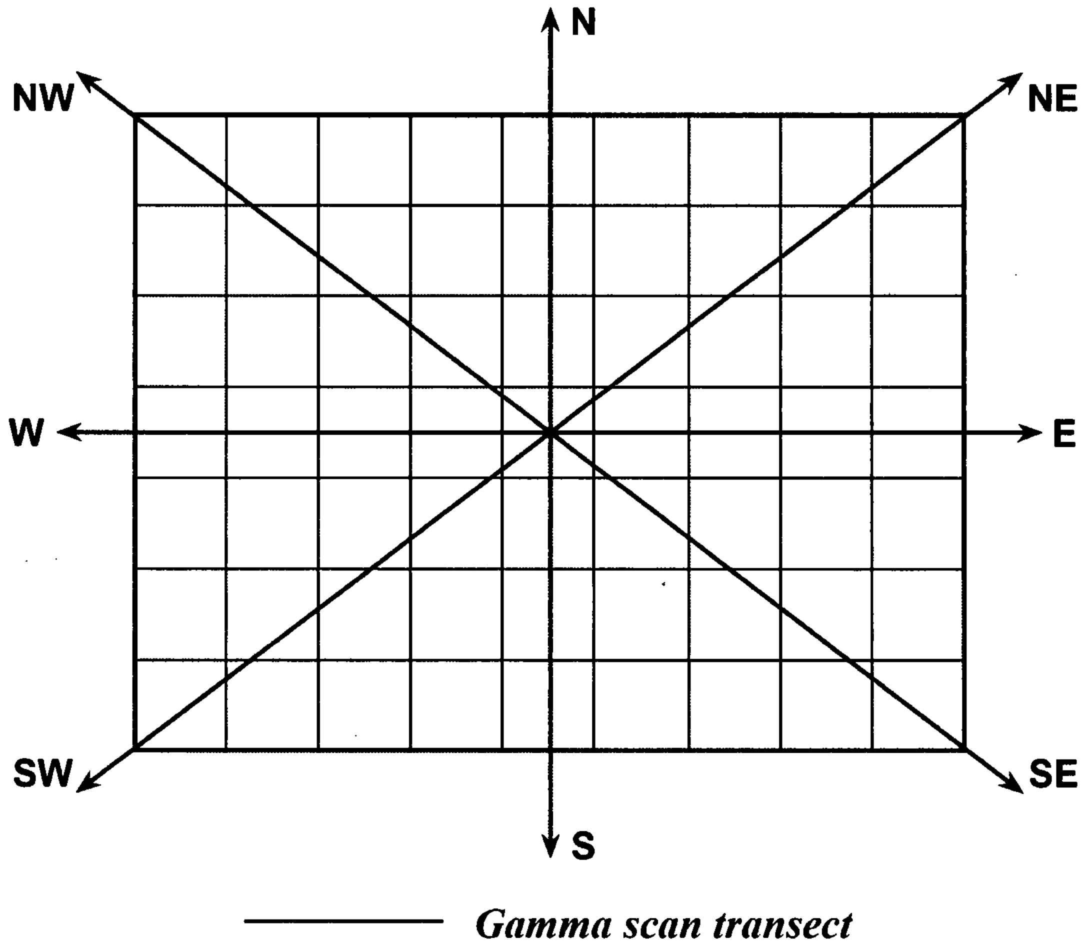


Figure 3-6. Recommended Cartesian Grid with Gamma Scan Transects

3.1.1.7. Radon Flux Measurements

Current Guidance

Section 1.1.6 of the current guidance provides the following information regarding radon flux measurements:

> *Radon-222 flux measurements should be made in three separate months during normal weather conditions in the spring through the fall when the ground is thawed. The measurements should be made at the center of the milling area and at locations 750 and 1500 meters from the center in each of the four compass directions.*

Measurements should not be taken when the ground is frozen or covered with ice or snow or following periods of rain.

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justification are provided regarding radon flux measurements during the preoperational monitoring phase in the revised RG 4.14.

A. Recommendation: Radon flux measurements should be eliminated from the future revision of RG 4.14.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: No technical bases have been identified by ORAU to support the existing guidance for performing radon flux measurements during the preoperational monitoring phase at a uranium recovery facility (specifically those facilities that include tailing impoundments as part of their design). Furthermore, the current guide does not provide recommendations for measuring radon flux during the operational monitoring phase, and no technical bases have been identified to support the inclusion of radon flux measurements during the operational phase. (Refer to Section 3.3.8.)

The NRC regulatory requirements in 10 CFR 40, Appendix A, Criterion 6, provide the technical bases for excluding radon flux measurements from the future revision of RG 4.14. The NRC regulatory requirements in Criterion 6 apply to active (UMTRCA Title II) sites to demonstrate compliance with a radon-222 average release rate (from uranium byproduct material) of 20 picocuries per square meter per second (pCi/m^{2}s) on the earthen covers (or approved alternative) placed over tailings or wastes at the end of milling operations. Specifically, Criterion 6(1) states the following:

In disposing of waste byproduct material, licensees shall place an earthen cover (or approved alternative) over the tailings or waste ***at the end of milling operations*** *and shall close the waste disposal area in accordance with the design.*

According to the current language in 10 CFR 40, Appendix A, Criterion 6, the focus is on decommissioning and reclamation, i.e., post-operational activities, rather than preoperational or operational activities at uranium mill tailings sites. These post-operational activities are outside the scope of the current and future revision of RG 4.14.

10 CFR 40, Appendix A, Criterion 6, does not discuss the subtraction of a background radon flux measurement or value in determining the radon-222 average release rate of 20 pCi/m^{2}s cited in the regulation. Background radon flux measurements are not considered in demonstrating compliance with the radon-222 average release rate. Therefore, the radon flux measurements recommended in the current RG 4.14 for the preoperational monitoring program should be removed from the future revision.

Applicants for new facilities have proposed eliminating radon flux measurements when the facility does not include tailings impoundments. NRC staff has concurred with the applicants' technical justification for not performing these measurements.

Even though the future revision of RG 4.14 will exclude radon flux measurements, active uranium recovery facilities are still required to comply with 10 CFR 40, Appendix A, Criterion 6. For active uranium mill tailings sites, NRC Regulatory Guide 3.64, *Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers* (NRC 1989), describes methods acceptable to the NRC staff for calculating radon fluxes through earthen covers and for calculating the resulting minimum cover thickness needed to meet NRC and EPA standards.

3.1.2. Frequency and Analysis of Preoperational Samples

The title of this section has been expanded from the current wording in RG 4.14 to include not only the analysis of preoperational samples, but the frequency associated with the collection of these samples.

<u>Current Guidance</u>

Section 1.2 of the current guidance provides the following information for the analysis of preoperational media samples:

> *Air particulate samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.*
>
> *Air samples collected for radon should be analyzed for radon-222.*

The results of analyses of air samples should be used to determine the radionuclide concentrations for the sampling locations.

All ground-water samples collected near the tailings area should be analyzed for dissolved natural uranium, thorium-230, radium-226, polonium-210, and lead-210. Ground-water samples from sources that could be used as drinking water for humans or livestock or crop irrigation should also be analyzed for suspended natural uranium, thorium-230, radium-226, polonium-210, and lead-210.

Surface-water samples from water impoundments should be analyzed quarterly for natural uranium, thorium-230, and radium-226 and semiannually for lead-210 and polonium-210. The samples should be analyzed separately for dissolved and suspended radionuclides.

Surface-water samples from flowing surface water should be analyzed monthly for natural uranium, thorium-230 and radium-226 and semiannually for lead-210 and polonium-210. The samples should be analyzed separately for dissolved and suspended radionuclides.

The results of analyses of water samples should be used to determine the radionuclide concentrations for the sampling locations.

Vegetation, food, and fish (edible portion) samples should be analyzed for natural uranium, thorium-230, radium-226, lead-210, and polonium-210.

All soil samples should be analyzed for radium-226. Soil samples collected at air particulate sampling locations and ten percent of all other soil samples (including at least one subsurface set) should be analyzed for natural uranium, thorium-230, and lead-210. Analysis of extra soil samples may be necessary for repeat samples collected at locations disturbed by site excavation, leveling, or contouring.

Sediment samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.

Recommendations, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justification are provided regarding the frequency and analysis of samples during the preoperational monitoring phase in the revised RG 4.14.

A. **Recommendation**: The analysis of Po-210 in all collected media samples should be eliminated from the next revision of RG 4.14.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Regulatory Guide 4.14, Revision 1, currently recommends analysis for Po-210 in some, but not all, environmental media (surface and ground water, and vegetation, food and fish). The analysis for this radionuclide also varies between the preoperational and operational programs. For the future regulatory guide revision, the continued need to analyze Po-210 in these media and all other relevant media samples (soil, air particulates) was extensively evaluated.

Five technical options were explored, including: 1) leaving the suite of analysis in the current regulatory guide "as is"; 2) performing an analysis for Po-210 every 5 years; 3) performing routine Po-210 analyses on all (primary and secondary) environmental pathways during the preoperational phase and a follow-up analysis every 5 years during the operational period; 4) performing a Po-210 analysis for air and water (the primary environmental pathways) during the preoperational phase with a follow-up analysis performed on the remaining environmental pathways every five years; and 5) eliminating Po-210 completely from all environmental pathways and analysis.

Several issues pertaining to both a qualitative and quantitative Po-210 evaluation were considered including the nature of facility operations at each uranium recovery facility, assumptions regarding the presence or absence of radioactive equilibrium in the uranium decay series, implementation considerations, sampling and analytical costs, impact of dose conversion factors on the dose contribution and dose significance, and pathway analysis. "Qualitative" refers to strictly identifying the presence of Po-210 in the sample versus determining the concentration of Po-210 in the sample medium. Evaluation of these factors resulted in technical arguments supporting both the inclusion and exclusion of Po-210.

While advantages to a prospective analysis during the preoperational phase were identified to assess the need for subsequent Po-210 sampling and analysis during the operational phase, ORAU concludes that a compelling technical argument does not exist for including Po-210 in a routine and continuous environmental monitoring program of all media at uranium recovery facilities. Ultimately, the analysis for Pb-210 in all environmental pathways is considered sufficient to identify the presence of Po-210 as an immediate decay product in associated with uranium recovery pathways. Therefore, to promote consistency between the preoperational and operational programs, Po-210 is excluded from further consideration in this document.

3.1.2.1. Air Samples

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the frequency and analysis of preoperational air samples in RG 4.14.

A. Recommendation: The revised guidance should retain natural uranium (U-nat), Th-230, Ra-226, and Pb-210 as airborne particulates for analysis purposes.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The radionuclide listing in the current guidance is technically defensible based on radionuclides anticipated in uranium ore (from the uranium series). The current listing essentially covers the complete uranium series (i.e., from the top of the decay chain beginning with uranium-238 through the long-lived decay product lead-210 near the very end of the chain).

B. Recommendation: The current guidance should be updated to include examples of the methods to analyze air samples for radiological particulates and radon; however, the applicant is responsible for choosing, defining, and defending the methods and frequency of analyses proposed for evaluation to the NRC.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Some examples of methods to analyze air samples (particulates and radon) are provided here and should also be provided in the revised guidance, however, it is the applicant's responsibility to choose, define, and defend the proposed methods and frequency.

The analysis of radiological air particulate samples depends on the selection of collection media (e.g., air filters).

The Multi-Agency Radiological Laboratory Protocols Manual (MARLAP) (NRC 2004) is an extensive multi-volume document that provides guidance in a number of technical areas. It contains a methodology, for example, to collect air samples and recommends that the choice of air filters will depend on the physical and chemical properties of the materials to be collected and counted.

ATSDR 1999 describes field measurement methods and analytical methods that are available for detecting, measuring, and/or monitoring uranium in environmental samples.

For field measurements of air filters containing particulates, a portable alpha scintillation detector (e.g., ZnS) equipped with a count rate meter may be used; if low detection limits are necessary, a gas-flow proportional counter may be used (ATSDR 1999; NRC 2004). Portable survey instruments can provide an immediate estimate or measurement of the level of activity that may be present in a sample (ATDSR 1999). However, there are limitations related to the measurement of uranium when using portable survey instruments and these are discussed in ATSDR 1999. ORAU believes that understanding these limitations is important, as portable instrumentation used in a field setting for evaluating air samples is not preferred: qualitative, rather than quantitative, assessment results are typically generated by this approach. For this reason, analytical (quantitative) methods in a laboratory setting are recommended.

As stated in ATSDR 1999, a variety of laboratory analysis methods have been used to quantify the total uranium present or its individual isotopes. The radiological analytical methods emphasize high resolution alpha spectrometry, although gamma-ray spectrometry can be used under the appropriate conditions. The chemical methods which are frequently used include spectrophotometry, fluorometry, and kinetic phosphorescence, with the addition of various mass spectrometer applications (ICP-MS, AES-MS, and accelerator-MS).

In addition to quantifying the total uranium or its isotopes, the radioanalytical methods such as alpha spectrometry and gamma spectrometry can be used to quantify the progeny of uranium.

For economic and logistical reasons, commonly used methods to monitor air concentrations of radon at uranium recovery facilities employ passive track-etch detectors. Track-etch detectors are typically comprised of a plastic material and available in several different configurations and sensitivities. The detectors form tracks when bombarded by alpha particles. Once processed and developed, the tracks become visible, are counted using a microscope, and the radon concentration related to the number of tracks using a pre-established calibration factor (tracks/square millimeter per pCi/liter-day). Track-etch detectors are not immune to various field issues, including elevation sensitivity, which if unaccounted for, may affect the number of recorded tracks and resultant concentration. Additional information on measuring radon and its progeny, including MDC considerations, is provided elsewhere in this document.

3.1.2.2. *Water Samples*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the frequency and analysis of preoperational water samples in RG 4.14.

A. Recommendation: The current guidance should be revised to include sampling of both radiological and non-radiological compounds to meet ground water protection standards per 10 CFR 40, Appendix A. (See Recommendation B for non-radiological constituents.)

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that ground water samples collected during the preoperational monitoring phase near a tailings area should be analyzed for dissolved U-nat, Th-230, Ra-226, Pb-210, and Po-210. The same radionuclide set is cited for analysis of drinking water (ingested by humans or livestock) or when used for crop irrigation. (The only exception is the substitution of suspended uranium for dissolved uranium in the analysis.) With the exception of Po-210, this suite of radiological contaminants is appropriate and should be retained for conventional and heap leach facility types. Po-210 is being eliminated based on information provided in an earlier recommendation. (See the discussion below related to the radiological suite examined for ISR facilities, which was ultimately rejected in favor of the identical analysis for conventional and heap leach facilities.)

Uranium, Th-230, Ra-226, and Pb-210 are recommended for analysis during the preoperational monitoring phase to fully establish site background values. Uranium should be analyzed since it is the element being extracted. Thorium (Th-230) is inherently associated with certain uranium ores (IAEA 1993).

The IAEA (IAEA 2002) mentions the presence of Th-232 in uranium ores; however, this appears to be an uncommon situation and not normally encountered in uranium recovery operations in the United States. Typically, the uranium recovery process tends to concentrate the natural uranium products. For this reason, no strong technical basis currently exists to require applicants to analyze for Th-232 (and its immediate decay product Ra-228).

Th-232 is present naturally in thorium ores and decays into radium (Ra-228) via alpha emission. Ra-228 and gross alpha measurements are included in 10 CFR 40, Appendix A, Criterion 5C, *Maximum Values for Ground-Water Protection*, and are required to be monitored in drinking water sources during the operational phase; thus, a background assessment of these parameters is recommended during the preoperational phase. However, NUREG-1569 (NRC 2003a) notes that many applicants have decided not to sample for thorium. This is acceptable if an appropriate technical basis is provided for excluding it from the list of sampled constituents.

The review of appropriate radioanalytical sampling methods for ISR facilities included consideration of whether radon in water sources should be monitored. Radon is a naturally occurring radioactive element at uranium extraction facilities since it is a product of radioactive decay of uranium. Radon gas can accumulate in ground water and be brought to the surface as a result of ISR operations. When water that contains radon reaches the surface, it readily volatilizes to the atmosphere. At ISR facilities, radon brought to the surface that stays in the ground water is not attracted to the ion exchange resin and may be recycled to the subsurface ore horizon (Powertech Uranium Corporation 2012). This implies that elevated radon could be present in a ground water excursion at ISR facilities. However, radon is not recommended as an addition to the radioanalytical suite for water sampling for any of the three facility types for the following reasons:

- Potential receptors for radon in ground water might include private drinking water wells and surface water bodies. However, excursion monitoring of indicator chemicals would detect an excursion from an ISR mining operation and allow for mitigation to occur prior to any contaminants from mining operations reaching private wells. It is worth noting that a study of radon in ground water in 50 private wells near a uranium ISR mining operation in South Texas concluded that there was no correlation between measured radon concentrations and distance or direction from the mining site (Fernandez et al. 2012). Therefore, sampling for radon in ground water does not appear to be warranted and is not recommended. Additional research would be needed to make a definitive recommendation.

- Radon is readily volatilized during turbulent mixing of water in air; therefore, sampling for radon in surface water is not recommended.

However, if radon is included in the suite of radiological analysis for water samples, the following guidelines are recommended. Water samples for radon analysis should be collected using a flow-through cell with the sample collected in a glass scintillation vial with no headspace to minimize loss through volatilization. The standard method for radon analysis in water is analytical method EPA 913 Liquid Scintillation (EPA 1991). However, alternatives may be proposed.

B. Recommendation: The current guidance should be updated to include the analysis of non-radiological contaminants associated with the preoperational water sampling program.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Water sampling for hazardous constituents should include anticipated releases of trace elements and contaminants associated with the uranium ore recovery process. 10 CFR 40, Appendix A, Criterion 13, provides an extensive listing of hazardous constituents that should be evaluated "if standards must be set and complied with if the specific constituent is reasonably expected to be in or derived from the byproduct material and has been detected in ground water." As the NRC does not consider the list (taken from 40 CFR 192) to be complete, additional constituents should be evaluated and included on a case by case basis. In brief, all appropriate analytical constituents associated with uranium recovery should be included to provide sufficient characterization of background ground water and surface water such that operational impacts to ground water can be detected and mitigated as required.

Chemicals associated with uranium recovery vary based upon the process chemistry utilized. Heap leach facilities generally use dilute sulfuric acid to extract the uranium. However, there are currently no licensed heap leach uranium recovery facilities in the United States (NRC 2012c). Processes that utilize acids to extract uranium from ore commonly produce sulfates, nitrates, and chlorides in the residual waste material, while processes that utilize alkaline solutions to extract uranium produce carbonates. Silica is also produced from alkaline solutions, however it is only associated with ISR facilities (NAS 2011).

Table 3-2 (from NRC 2003a) provides a summary of water monitoring parameters typically monitored during the preoperational phase at ISR facilities.

Table 3-2. Typical Baseline Water Quality Indicators to be Determined during Preoperational Data Collection[1]

Trace and Minor Elements		
Arsenic	Iron	Selenium
Barium	Lead	Silver
Boron	Manganese	Uranium
Cadmium	Mercury	Vanadium
Chromium	Molybdenum	Zinc
Copper	Nickel	
Fluoride	Radium-226[2]	
Common Constituents		
Alkalinity	Chloride	Sodium
Bicarbonate	Magnesium	Sulfate
Calcium	Nitrate	
Carbonate	Potassium	
Physical Indicators[3]		
Specific Conductivity	pH	Total Dissolved Solids
Radiological Parameters		
Gross Alpha	Gross Beta	

[1] Excerpted from NUREG-1569 (minor edits made to Footnote 2 for consistency in using background terminology in this TBD), Section 2.7, Table 2.7.3-1 (NRC 2003a).
[2] If the site sampling indicates the presence of Th-232 then Ra-228 should be considered in the background sampling or an alternative may be proposed.
[3] Field and laboratory determination

C. Recommendation: While the sampling analysis intervals currently provided in RG 4.14 remain acceptable for conventional uranium mills, applicants should be afforded flexibility to offer alternative time intervals to conduct the analyses for all types of uranium recovery facilities.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The guidance currently cites varying time periods to conduct the analysis ranging from monthly to quarterly based on the water source. As long as analytical protocols used by the applicants are technically sound and acceptable results are provided to NRC staff, flexibility in this area should be permitted in the updated guidance.

D. Recommendation: The current guidance should be revised to include sampling of both radiological and non-radiological compounds. (See Recommendation E for non-radiological constituents.) The radioanalytical suite for surface water samples should be site-specific and established based on consideration of operational processes and type of uranium recovery facility.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance describes surface water sources originating from either water impoundments or flowing water. The guidance states that *"Surface-water samples...should be analyzed...for natural uranium, thorium-230, and radium-226 ... lead-210 and polonium-210. The samples should be analyzed separately for dissolved and suspended radionuclides."*

As identified previously for ground water, applicants should include all appropriate analytical constituents to provide sufficient characterization of background surface water such that operational impacts to surface water can be detected and mitigated as required. Gross alpha and beta analyses should be added as these analyses provide initial radiological information on gross (non-radionuclide-specific) levels.

E. Recommendation: The current guidance should be updated to include the analysis of non-radiological contaminants for surface water associated with the preoperational water sampling program as applicable to the recovery process and type of facility.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The analytical suite should be site-specific and established considering operational processes and type of facility. Refer to 10 CFR 40, Appendix A, Criterion 13 for an extended listing of hazardous constituents and Table 3-2 above for typical non-radiological water quality indicators during preoperational surface water data collection.

All appropriate analytical parameters should be included to provide sufficient characterization of background surface water such that operational impacts to surface water can be detected and mitigated as required.

3.1.2.3. Vegetation, Food, and Fish Samples

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the frequency and analysis of preoperational vegetation, food, and fish samples in RG 4.14.

A. Recommendation: Applicants should continue to analyze for U-nat, Th-230, Ra-226, and Pb-210 in edible vegetation, food, and fish samples but eliminate analysis for Po-210.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Uptake of U-nat, Th-230, and Ra-226 has been previously reported in the literature in vegetation near uranium recovery facilities (Rumble et al. 1986; Soudek et al. 2004; Cerne et al. 2010; Rayno 1983; Marple 1980; Ibrahim et al. 1992). Additionally, the IAEA indicates that initial analyses should include U-nat, Th-230, Pb-210, Th-232, and Ra-226 (IAEA 2002).

Because the uranium decay series is of particular interest for uranium recovery facilities, analysis of U-nat, and decay progeny including Th-230 and Ra-226 can be defended with little difficulty. A similar argument can be made for Pb-210 near the end of the decay chain.

Po-210 is being eliminated from the analysis of vegetation, food, and fish based on information provided in Section 3.2.

3.1.2.4. Soil and Sediment Samples

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the frequency and analysis of preoperational samples of soil and sediment in RG 4.14.

A. **Recommendation:** The analysis in the current guidance should continue for radionuclides specified in soil and sediment (U-nat, Th-230, Ra-226, and Pb-210). Because no changes are recommended, these two media are discussed concurrently.

   Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

   Justification/Discussion: As mentioned previously, Ra-226 and Pb-210 have been utilized as environmental indicators of contamination in terrestrial and aquatic ecosystems. Due to the potential of dispersion via wind erosion of stored ore and tailings, U-nat and Th-230 should also be analyzed to establish a background of principal radiological contaminants in soil. This is also of particular interest in ISR facilities where the recovery operation occurs within the location of the ore body and nearby soil may be affected by seepage and excursions of contaminants.

3.1.3. Operational Monitoring

This section of the TBD discusses operational monitoring aspects that complement the preoperational monitoring period. Areas discussed include air, water, soil, sediment, direct radiation, vegetation, food, and fish. While not an area of detailed emphasis within this TBD, if a uranium recovery facility (e.g., ISR) includes land application (land irrigation) of process waste water, the impacts to environmental media such as soil and vegetation should be evaluated, particularly if treated water is applied to fields where food for human/animal consumption may be possible.

In this section, the word "applicant is replaced with the word "licensee" under the assumption that during the operational monitoring period the facilities are licensed by the NRC or Agreement States.

Current Guidance

Section 2 of the current guidance states the following for the operational monitoring program:

An acceptable monitoring program to be conducted during construction and after the beginning of milling operations is described below and summarized in Table 2. The results of this program should be summarized quarterly and submitted to NRC semiannually pursuant to § 40.65 of 10 CFR Part 40. An acceptable reporting format is shown in Table 3.

Recommendations, Applicability, and Justifications/Discussions

It is recognized that some of the terminology (e.g., mill site, milling operations, tailing areas and tailing impoundments) used in the current guidance may not be applicable to in situ or heap leach facilities and no technical justification for changing the terminology is included in this document. However, the revised guidance should include appropriate terminology as applicable for each facility type. The following recommendations, applicability, and justifications are provided to enhance the operational monitoring section in RG 4.14.

A. Recommendation: The current guidance to continue environmental monitoring during construction and after the beginning of milling operations should be retained in the upcoming revision of NRC RG 4.14 and expanded to other types of uranium recovery facilities.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: An adequate operational monitoring program should be performed throughout the construction and operating phases of the mill as required by 10 CFR Part 40, Appendix A, Criterion 7. Heap leach and ISR facilities require such a program as well. The operational monitoring program will, for the most part, be a continuation of the preoperational monitoring program, and may include sampling modifications as appropriate to address any regulatory, facility, and public needs.

The operational radiological monitoring programs for conventional mills and heap leach facilities, and in situ recovery facilities are summarized in Tables C-1 and C-2 respectively, of Appendix C. Furthermore, Tables C-3 and C-4 of Appendix C describe the preoperational non-radiological monitoring program for conventional mills and heap leach facilities, and ISR facilities, respectively. As identified previously, non-radiological monitoring programs would include ground water and surface water only.

B. Recommendation: Operational monitoring should include the monitoring of non-radiological contaminants from surface and ground water sources. (This was also recommended for the preoperational monitoring section in this document.)

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Refer to Recommendation B in Section 3.1.1.

C. Recommendation: The reporting format in Table 3 of the current guidance should be updated to incorporate all types of uranium recovery facilities.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance, stating that the results of the operational program should be summarized quarterly and submitted to NRC semiannually pursuant to § 40.65 of 10 CFR Part 40, should be retained in the revision of NRC RG 4.14. The licensees should summarize the results of the operational monitoring program on a quarterly basis as indicated in RG 4.14, and submit a report to the NRC semiannually pursuant to 10 CFR Part 40.65, *Effluent Monitoring Reporting Requirements*. Table 3 in RG 4.14, containing a reporting format for conventional mills, should be modified to include heap leach and ISR facilities. This table should include pertinent information based on an acceptable reporting format (e.g., include other acceptable methods, and units) currently used by uranium recovery facilities. It should not be necessary to create tables for each facility, since the table can be structured generically for use by the three types of facilities.

An acceptable reporting format is presented in Appendix D.

D. Recommendation: Based on the recommendations made for the preoperational and subsequently the operational monitoring program, Table 2 of the current guidance is inadequate and should be updated.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Based on availability of newer, more current information, Table 2 of the current guidance should be updated according to the modifications suggested in the preoperational monitoring section. Separate tables, also based on newer information, should be developed summarizing the operational monitoring program for each type of facility.

3.1.3.1. Stack Sampling

Current Guidance

Section 2.1.1 of the current guidance states the following for the operational stack sampling program:

> *Effluents from the yellowcake dryer and packaging stack should be sampled at least quarterly during normal operations. The sampling should be isokinetic, representative, and adequate for determination of the release rates and concentrations of uranium. The sampling should also be adequate for the determination of release rates and concentrations of thorium-230, radium-226, and lead-210 if this data cannot be obtained from other sources.*
>
> *Other stacks should be sampled at least semiannually. The samples should be representative (not necessarily isokinetic) and adequate for the determination of the release rates and concentrations of uranium, thorium-230, radium-226, and lead-210.*
>
> *All stack flow rates should be measured at the time of sampling.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the stack sampling section in RG 4.14.

A. Recommendation: The "at least" quarterly sampling frequency cited in the current guidance for effluent emissions from the yellowcake dryer (i.e., gas-fired multihearth dryer) and packaging stack during normal operations should be removed and the language modified to consider newer yellowcake dryer designs (i.e., vacuum dryer).

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current recommendation is applicable for older facilities using a gas-fired multihearth (thermal) yellowcake dryer. NRC 2009c states that these types of dryers (multihearth) operate at relatively high temperatures and produce combustion products that are normally scrubbed before they are released into the atmosphere. Newer facility designs include a vacuum dryer for yellowcake. The vacuum dryer does not have a stack; rather, it employs a baghouse/dust filter system to capture particulates. The air from the baghouse is usually routed to the dryer offgas line and scrubber (NRC 2009c). Therefore, dust emissions from drying yellowcake may be assumed to be negligible under normal operations (NRC 2003a and 2009a).

In addition to operational design changes with new conventional mill facilities, newer ISR facilities (e.g., Nichols Ranch 2007; EMC 2007; Crow Butte 2007), and a proposed new heap leach facility (i.e., Titan Uranium USA Inc. 2011) employ vacuum dryers for yellowcake to significantly reduce particulate emissions to negligible quantities during normal operations (e.g., Nichols Ranch 2007; EMC 2007; Crow Butte 2007; Strata Energy 2010). Since essentially minimal releases of particulates may occur during standard operations, and the vacuum dryer does not have a stack, sampling at conventional mills and possibly heap leach facilities may be limited to other stacks (if present) which may have the potential to release particulates as part of their operations.

Typically, at nuclear materials facilities, emission control and monitoring devices are installed to limit effluent releases of radioactive material and assess any residual contamination released to the environment. 10 CFR Part 40, Appendix A, Criterion 8, requires that milling operations be conducted so that all airborne effluent releases are ALARA. Therefore, it is recommended that uranium recovery facilities that have stacks incorporated into their design install emission control and monitoring devices in the ventilation system to comply with Criterion 8. Support for this recommendation exists in American National Standards Institute (ANSI) N13.1 (2011), *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities,* RG 4.16 Rev. 2 (2010), *Monitoring and Reporting Radioactive Materials in Liquid and Gaseous Effluents from Nuclear Fuel Cycle Facilities, and RG 1.21 Rev.2 (2009), Measuring, Evaluating, and Reporting Radioactive Material in Liquid and Gaseous Effluents and Solid Waste.* ANSI N13.1 is applicable to stacks and ducts at nuclear facilities and is being applied here to uranium recovery facilities. The term "duct" does not refer to interior ducting such as HVAC ducts; rather a stack or duct is intended here to be the point of release from a restricted area to an unrestricted area [e.g., a release from within the facility to the outside]) and includes associated components of a separate and independent ventilation system such as piping attached to the point(s) of release and venting of the effluent.

ANSI N13.1 (2011) is also used as the basis for the proposed change to the sampling frequency. Sections 5.2.2.2 and 4.4.2 of N13.1 refer to sampling "continuously, at a frequency that permits an evaluation of concentration in near real-time, or at intervals that comply with regulatory requirements" and "sampling at an appropriate frequency," respectively. The word "appropriate" is repeated elsewhere in N13.1. ORAU is unaware of a specific regulatory requirement for stack sampling frequency, but typically a graded approach should be used (e.g., the greater the potential dose to the public, the greater the sampling frequency).

If a uranium recovery facility includes a gas-fired multihearth dryer which typically has a stack associated with it, then effluent monitoring should be performed at this facility at a frequency established and agreed to between the licensee and the NRC. Alternatively, if a facility includes a vacuum dryer which does not have a stack, then effluent monitoring will not be necessary. In this instance, where the air stays inside the room in which the vacuum dryer is located, it may be considered an "occupational radiation safety" issue as opposed to an "environmental" issue. Occupational issues, while outside the scope of the RG 4.14 revision, may require further scrutiny by the NRC to notify licensees that while effluent monitoring is not required, scenarios such as opening doors or windows to reduce radon levels (or other similar scenarios) are not acceptable. NRC RG 4.16 (2010), Section 2.1 ("Gaseous Effluents"), notes that "Licensees should consider gaseous effluents from all operations associated with the facility…." and "Licensees may use a graded approach to determine sampling and monitoring methods and frequencies." A more robust environmental monitoring program should also be considered in the absence of effluent monitoring.

In summary, it is recommended that the licensee should be responsible to describe their facility in the context of the need (if a need exists) for effluent monitoring to satisfy Part 40, Criterion 8, and a proposed sampling frequency based on that need. This information should be submitted to the NRC as part of the license application review and approval process.

B. Recommendation: The recommendation in the current guidance citing isokinetic, representative and adequate sampling for determination of the release rates and concentrations of uranium should be retained with the exception of isokinetic sampling. However, the language should be modified to acknowledge these conditions may not be satisfied in all cases, i.e., for all facilities using a vacuum dryer. The current language is associated with the use of multihearth dryers for yellowcake.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: For facilities releasing particulates during normal operations, it is important that the collected sample be representative of the effluent. Representative sampling should be retained based on a review of ANSI N13.1 (2011) and NRC regulatory guides, including RG 1.21 and 4.16.

In order to obtain a representative sample, the sampling must be performed at a location where the gases and particulates are well mixed. Isokinetic sampling for particulates is typically and frequently considered a requirement when the recommendations of the American National Standards Institute for stack and duct sampling (ANSI N13.1-1969, *Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities* and subsequent updates) are followed. Isokinetic sampling, however, only ensures that a representative sample of particulates enters the nozzle. It does not guarantee that a representative sample is collected on the filter. Per the most recent version of ANSI N13.1 (2011), isokinetic sampling is not required for obtaining representative samples. The ANSI standard cities studies by McFarland and Rodgers (1993) that isokinetic operation is not a prerequisite for obtaining representative samples. Therefore, the requirement for isokinetic sampling has been eliminated.

Stack sampling for facilities using a multihearth (thermal) dryer for yellowcake should also be representative and adequate for determination of the release rates and concentrations of particulates. Isokinetic sampling is no longer required. Particulates such as U-nat, Th-230, Ra-226, and Pb-210 are likely or potential stack effluents from facilities employing a thermal yellowcake dryer. New uranium recovery facilities have a yellowcake vacuum dryer with a baghouse to collect the majority of particulates released during the drying process; therefore, particulates releases are negligible. This type of dryer does not employ a conventional stack in its design relative to facilities with a multihearth (thermal) dryer. Thermal dryers for yellowcake were normally used in old facility designs; the stack sampling had to be isokinetic (which is limited to particulates), representative, and adequate to determine the release rates and concentrations of particulates emitted during drying and packaging of yellowcake.

C. Recommendation: Language should be added that radon is the primary radioactive airborne effluent release at ISR facilities during normal operations.

Applicability: This recommendation is applicable to ISR facilities.

Justification/Discussion: In the case of ISR facilities using a vacuum dryer, radon gas is the primary airborne effluent released to the atmosphere. Radon can be released during wellfield drilling, production, CPP operations, resin transfer operations and aquifer restoration activities (NRC 2009c). ISR facilities monitor or propose monitoring radon at the environmental air monitoring stations, as opposed to monitoring radon as part of the central processing facility process equipment ventilation system or the general area ventilation system (Crow Butte 2007; Strata Energy 2010). Although this is the current acceptable practice at ISR facilities, there are conventional stack sampling methods to measure radon released at vents or stacks.

It is important to note that uranium recovery facilities are required to limit public exposure to air emissions (excluding radon and its progeny) to no greater than the dose constraint of 10 millirem per year (mrem/yr) cited in 10 CFR 20.1101(d), and NRC RG 4.20, Revision 1 (NRC 2012d). This requirement is satisfied through measurements or calculations. Radon and its progeny is not included in the air emission constraint, but it may evaluated for compliance with the air effluent limits in 10 CFR Part 20, Appendix B, Table 2 or by performing a dose assessment and comparing the results with the public dose limits in 10 CFR 20.

D. Recommendation: The current guidance should be updated to include information on the differences between ambient air sampling and stack effluent sampling or the importance of stack monitoring.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: During the operational phase, samples are collected directly from identified emission sources (e.g., building emission stacks or vents) and from the ambient air (typically at ground level) at or near the site boundary. Both types of air sampling are important components of an operational monitoring program and are similar in that they are used to determine the amount of radioactivity present in a given volume of air sampled. The concentration measured in the air or effluent is compared to regulatory requirements and dose constraints.

As noted previously, ANSI N13.1 is the standard frequently cited for sampling airborne radioactivity from stack effluents. The original version of the standard is ANSI N13.1-1969, *Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities.* The latest version of the standard is ANSI N13.1-2011, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities.*

Some general purposes for stack sampling include (ORAU 2010; ANSI N13.1):

- Demonstration of compliance with regulatory requirements and dose constraints (e.g., 10 CFR 20.1101[d], NRC RG 4.20, Rev. 1 [NRC 2012d])
- Development of the release rate (e.g., Bq/s, Ci/min) from a stack in order to estimate the dose to the public
- Identification of excessive concentrations being released that require corrective action
- Detection of long-term variations in releases which may indicate deteriorating equipment

Additional objectives are available in ANSI N13.1. Other air sampling publications include: *Radioactive Air Sampling Methods* (Maiello and Hoover 2011); *Radioactive Emissions from Yellowcake Processing Stacks at Uranium Mills* (EPA 1980); and *Air Sampling Instruments for Evaluation of Atmospheric Contaminants* (Cohen and McCammon, Jr. 2001). The last reference is a comprehensive guide for the sampling of air contaminants in general (i.e., it is not limited to radioactive air contaminants). It discusses occupational and environmental air sampling and provides methods and instruments for particulates and gases. This reference has a chapter dedicated to sampling from ducts and stacks. In addition, EPA regulations for stack sampling include:

- 40 CFR 60, *Standards of Performance for New Stationary Sources (NSPS)*
- 40 CFR Part 60, Appendix A, *Test Methods*
- 40 CFR Part 61, Appendix B, Test Method 114-Test Methods for Measuring Radionuclide Emission from Stationary Sources

E. **Recommendation:** The current guidance for sampling stacks other than the yellowcake dryer and packaging stacks at least semiannually and recommending representative and adequate sampling, should be revised for conventional mills and heap leach facilities and updated to include an alternative sampling strategy for ISR facilities that primarily release radon gas.

Applicability: These recommendations are applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that stacks other than the yellowcake dryer and packaging stack should be sampled at least semiannually and that the samples should be representative (not necessarily isokinetic) and adequate for the determination of the release rates and concentrations of uranium, Th-230, Ra-226, and Pb-210. Based on ANSI N13.1 (2011), it is recommended that the "at least semiannually" frequency be eliminated (see Recommendation A in Section 3.1.3.1). The sampling frequency should be determined and defended by the licensee. It is also recommended to retain representative sampling but eliminate isokinetic sampling for conventional mills and heap leach facilities.

The yellowcake dryer and packaging stack at conventional mills and heap leach facilities should continue to be monitored for particulate effluent releases using an acceptable stack sampling procedure (e.g., ANSI N13.1) (see Recommendation A). Grab sampling may also be utilized, as long as considerations such as sampling location(s) and a reasonable sampling frequency are adopted.

At ISR facilities (using vacuum dryers), radon gas is the primary radioactive effluent emission during normal process operations (for example, from processing tank venting during normal operations [Crow Butte 2007 and EMC 2007]). Therefore, ISR facilities require an alternative sampling strategy. As mentioned in Recommendation C of this section, radon release to the environment as a result of operations may be monitored at the environmental air radon monitoring stations.

3.1.3.2. Air Samples

Current Guidance

Section 2.1.2 of the current guidance states the following for the operational air sampling monitoring program:

> *Air particulate samples should be collected continuously at (1) a minimum of three locations at or near the site boundary, (2) the residence or occupiable structure within 10 kilometers of the. site with the highest predicted airborne radionuclide concentration, (3) at least one residence or occupiable structure where predicted doses exceed 5 percent of the standards in 40 CFR Part 190, and (4) a remote location representing background conditions. The sampling locations should be the same as those for the preoperational air samples (see Section 1.1.1). The sampling should be adequate for the determination of natural uranium, thorium-230, radium-226, and lead-210.*
>
> *Normally, filters for continuous ambient air samples are changed weekly or more often as required by dust loading.*
>
> *Samples should be collected continuously at the same locations, or for at least one week per month, for analysis of radon-222.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the operational monitoring of air samples:

A. Recommendation: Air sampling locations should be consistent with the siting criteria in Section 3.1.1.1

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The operational air sampling program as described in the current RG 4.14 is primarily a continuation of the preoperational program. Following the onset of facility operations, the operational air sampling locations should be identical as those identified in the preoperational phase (refer to Section 3.1.1.1). Upon a comprehensive assessment, the licensee could modify the operational monitoring program to add or remove sampling locations as appropriate. However, prior to making modifications to the sampling locations, the licensee should provide the NRC with a technical basis for inclusion or removal.

B. Recommendation: Radon monitoring locations should be consistent with the preoperational monitoring program (see Recommendation I in Section 3.1.1.1).

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The operational radon monitoring locations should match the air particulate sampling locations, as described in the current RG 4.14. The additional radon detectors established during the preoperational phase should also be maintained during operations. During the operational phase, additional sampling locations could be identified (see Recommendation A in this section), requiring modifications to the operational air sampling program. If air particulate sampling locations are added or removed, the radon sampling locations should remain consistent and be co-located with air particulate locations.

Radon monitoring efforts may also be reduced based on historical data provided that the remaining radon monitoring stations adequately represent the current conditions at the wellfields and/or header houses. Upon a comprehensive assessment, the licensee could modify the operational monitoring program to add or remove radon monitoring locations as appropriate. However, prior to making modifications to the monitoring locations, the licensee should provide the NRC with a technical basis for inclusion or removal.

C. Recommendation: The frequency of replacing air particulate filters should be consistent with the approach defined during the preoperational monitoring phase and radon detectors should continue to be deployed for at least three months.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The licensee should have defined a frequency for replacing air particulate filters during the preoperational phase (see Recommendation G in Section 3.1.1.1). This approach should continue throughout the operational phase.

The length of deployment of radon detectors during the operational period should match that of the preoperational phase (see Recommendation I in Section 3.1.1.1).

3.1.3.3. Water Samples

Current Guidance

Section 2.1.3 of the current guidance states the following for the operational water sampling program:

> *Samples of ground water should be collected from at least three sampling wells located hydrologically down gradient from the tailings area and from one background well located hydrologically up gradient. The samples should be collected monthly through the first year of operation and quarterly thereafter from the same downslope and background wells that were used for preoperational samples (see Section 1.1.2).*
>
> *Samples should be collected at least quarterly from each well within two kilometers of the tailings area that is or could be used for drinking water, watering of livestock, or crop irrigation.*
>
> *Samples should be collected at least quarterly from each onsite water impoundment (such as a pond or lake) and any offsite water impoundment that may be subject to seepage from tailings, drainage from potentially contaminated areas, or drainage from a tailings impoundment failure.*
>
> *Samples should be collected at least monthly from any surface water crossing the site boundary and offsite streams or rivers that may be subject to drainage from potentially contaminated areas or from a tailings impoundment failure. Stream beds that are dry part of the year should be sampled when water is flowing. Operational samples should be collected upstream and downstream of the area of potential influence.*
>
> *Any unusual releases (such as surface seepage) that are not part of normal operations should be sampled.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the operational monitoring of water samples in RG 4.14.

A. Recommendation: Sampling frequencies described in the current guidance for monitoring wells located hydrologically upgradient and downgradient and flowing surface water should be revised to "at least quarterly."

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance includes the following sampling frequencies.

- Monitoring wells located hydrologically upgradient and hydrologically downgradient should be sampled monthly for the first year and quarterly thereafter.
- Private wells should be sampled at least quarterly.
- Onsite and offsite water impoundments should be sampled at least quarterly.
- Flowing surface water should be sampled at least monthly.

Sampling at least quarterly is considered adequate for ground water and surface water samples. However, if seasonal variations were identified during preoperational sampling at a specific facility or if an excursion has occurred, an increased sampling frequency is appropriate. Also, in the case of flowing surface water bodies, an increased sample frequency may be necessary if any excursions have occurred or if sensitive receptors are present at downstream locations. The licensee may propose a different sampling frequency or change the sampling frequency with adequate justification and timely notification to the NRC. Operational sample results should be tracked and compared to preoperational sample results (and previous operational sample results) to determine changes and trends which should be explained by the licensee. Licensees should describe any variability associated with the results, describe the statistical tests used to analyze variability (for example the Mann-Kendall test), and explain the variability. Guidance such as NRC 1981b, ASTM 2005, and EPA 2009 can be used for assistance in determining appropriate statistical methods.

Ground water monitoring to establish background water quality for excursion monitoring and to establish restoration standards within a specific ISR wellfield before production is covered in NUREG-1569.

B. Recommendation: The sampling location guidance should be changed to recommend that the sampling locations default to those established for preoperational sampling. Reduced or additional proposed operational locations should be included in the license request.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Consistency in the locations for both preoperational and operational sampling is preferred as it provides an opportunity to compare results prior to and following operational facility startup. Sample locations can be eliminated or added as appropriate throughout the operational phase with appropriate notification and technical basis provided. For example, if ground water sampling indicates that an excursion has occurred, additional monitoring wells may be needed to characterize the excursion and monitor for corrective action. In brief, changes in conditions or to the operations of the uranium recovery facilities may result in changes in the monitoring plan. Accordingly, provisions need to be included in the revised guidance for these potential changes.

C. **Recommendation**: The current guidance stating that unusual releases should be sampled should be retained.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current guidance states that "any unusual releases (such as surface seepage) that are not part of normal operations should be sampled." Unexpected occurrences of contaminants should be investigated for cause to determine if mitigation is needed.

3.1.3.4. Vegetation, Food, and Fish Samples

Current Guidance

Section 2.1.4 of the current guidance states the following for the operational monitoring of vegetation, food, and fish samples:

> *Where a significant pathway to man is identified in individual licensing cases, vegetation, food, and fish samples should be collected as described below.*
>
> *Forage vegetation should be sampled at least three times during the grazing season in grazing areas in three different sectors having the highest predicted airborne radionuclide concentration due to milling operations.*

At least three samples should be collected at the time of harvest or slaughter or removal of animals from grazing for each type of crop (including vegetable gardens) or livestock raised within three kilometers of the mill site.

Fish (if any) samples should be collected semiannually from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by a tailings impoundment failure.

Recommendations, Applicability, and Justifications/Discussion(s)

The following recommendations, applicability, and justifications are provided to enhance the operational monitoring of vegetation, food, and fish samples in RG 4.14. The sampling method specified in Tables 1 and 2 of the current guidance (i.e., grab sampling), should continue to be recommended in the revised guidance. As mentioned in Chapter 4. Land Use Census of this TBD, the specific type of vegetation or livestock samples should be specified by using the common names. For example, a common name for a plant is "big sagebrush" and a common name for livestock is "cattle." The scientific name (genus/species) may be provided if it is readily available. Generic terms such as vegetation, plant, crops, or livestock should be avoided. This approach also applies to fish.

A. Recommendation: The locations and frequency described in the current guidance to obtain forage vegetation samples should be retained.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Radiological contaminants are predominantly dispersed via air and water sources. Multiple literature citations exist to document that airborne contaminants are directly deposited onto nearby vegetation and surface soils, (examples include Carvalho et al. 2007; Muscatello and Janz 2009; Peterson et al. 2002) while those dispersed via water transport are commonly absorbed in nearby soils and subsequently taken up by vegetation. Therefore, sampling of vegetation should be performed at the locations where the distributions of contaminants (via water and air) are expected to yield the highest concentration. Additional sampling locations may be warranted based on the site-specific characteristics and conditions.

Additionally, forage vegetation (including wetland plants) may be the principal food source for grazing and game animals. Therefore, due to the risk of ingestion of contaminated dairy and meat products by members of the public, forage vegetation should be collected during grazing periods. The collection of multiple vegetation samples during the grazing season may provide an assessment of possible build-up of contaminants in grazing areas and retention fraction of contaminants in grazing animals.

B. Recommendation: The language and recommendation in Footnote (o) from Table 2 of the current guide should be revised entirely to be consistent with the recommendations in RG 4.1 Rev. 2 associated with sample media. The revised language should be incorporated within the body of the main text under vegetation sampling in the revision of RG 4.14.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Footnote (o) from Table 2 states the following: "*Vegetation or forage sampling need be carried out only if dose calculations indicate that the ingestion pathway from grazing animals is a potentially significant exposure pathway (an exposure pathway should be considered important if the predicted dose to an individual would exceed 5% of the applicable radiation protection standard).*" This information only appears as a footnote and is never mentioned within the main text of the RG.

Currently, no regulatory requirements or technical bases have been identified to support the exact language in the existing guidance for sampling vegetation or forage during the operational monitoring phase. However, a technical basis exists in NRC RG 4.1 Rev. 2 to revise this language.

NRC RG 4.1 Rev. 2 includes the following about sample media in Sections 5a and 5e:

Section 5a, states "*...In general, sample media should be selected for environmental monitoring as outlined in NUREG-1301/1302. The REMP [Radiological Environmental Monitoring Program] need only include sample media that actually exists at a site and are utilized in sufficient quantities (consider availability and usage/consumption factors). However, if the site-specific land use census identifies a new important route of exposure that contributes more than 20% to the calculated individual dose as determined by Regulatory Guide 1.109, then sample media associated with the route of exposure should be added to the REMP.*"

The language in Section 5a of RG 4.1 Rev. 2 is aimed at adding a new route of exposure/sampling location. Similar language from Section 5a for adding a new route of exposure/sampling location has been included in Chapter 4. Land Use Census (Chapter 4 of the TBD).

Additionally, Section 5e indicates that *"The sample media associated with the ingestion pathway for gaseous releases should be monitored as outlined in NUREG-1301/1302. This includes sampling and analyzing sample media (i.e., milk, or if milk is not available, broad leaf vegetation) and other sample media if identified in accordance with Section 5.a above. For example, sampling of domesticated meat may be needed if the land use census shows that a significant amount of meat is raised locally, and an evaluation shows that meat consumption contributes a 20% dose increment to the total individual dose. Similarly, sampling meat from game animals may be necessary if hunting accounts for a significant amount of meat obtained for consumption (see usage factors in Regulatory Guide 1.109). If goat milk is produced locally (e.g., within 5 miles or 8 km) for human consumption, then sampling and analysis may be required if sufficient quantities are available for sampling purposes. However, if sufficient quantities are not available for sampling, then an alternate sample media should be sampled such as broad leaf vegetation."*

Section 5e discusses sampling media associated with the ingestion pathway and it refers to a 20% dose increment to the total individual dose. The 20% dose increment to the total individual dose is not a 20% dose increment from the limit of 100 mrem as defined in 10 CFR 20.1301 and 10 CFR 20.1302. It represents the dose increment from the previous sampling location that is being evaluated for replacement. If a new sampling location for food crop was identified in the same sector as the current food crop sampling point, but 1 mile closer to the release point, the applicant/licensee needs to evaluate the dose contribution to the current site and compare the potential dose contribution if the new sampling location was added to the program. For example, if the current food crop sampling location annual dose is 20 mrem and the potential new food crop sampling location is 25 mrem annually, then the potential new food crop sampling location is now more than 20% dose increment to the total individual dose. It is anticipated that the dose increment would differ for each site and for each location.

This 20% has different meaning compared to the 10% discussed in Recommendation B in Section 3.7 (i.e., MDCs for stack effluent samples should remain 10% of the appropriate concentration values in 10 CFR 20, Appendix B, Table 2).

In order to be consistent with RG 4.1 Rev 2, the current guide should be modified to specify vegetation or forage sampling in terms of the land use census. The suggested language for the future revision should be similar to the following: sampling of vegetation may be needed if the land use census shows that a significant amount of vegetables/crops are grown locally, and an evaluation shows that vegetable consumption contributes a 20% dose increment to the total individual dose.

C. **Recommendation:** The locations and frequency described in the current guidance to obtain crop samples (including those from vegetable gardens) or livestock samples should be updated to include the option to obtain samples of game animals.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Human consumption of livestock, game, and garden vegetables provides an indirect pathway for the intake of radiological contaminants. Edible portions of meat from livestock and game, as well as garden vegetables, should be analyzed to assess the transportation of contaminants in the food chain, and the potential effects of ingestion by members of the public.

The current guide specifies that: "At least three samples should be collected at time of harvest or slaughter or removal of animals from grazing for each type of crop (including vegetable gardens) or livestock raised within three kilometers of the mill site." This should be interpreted in the revised guide as one sample from each of three different livestock animals—e.g., cattle, sheep (if available)—used for human consumption within 3 km of the site boundary[3]. Alternatives to livestock are game and crops. Game animals should be included in the future guide, since hunting may be significant in areas where uranium recovery sites are typically located.

[3] For ISR facilities, samples should be collected within 3 km of the CPP, satellite facility, or any other facility that handles, stores, or processes large quantities of source materials.

D. Recommendation: The locations and frequency described in the current guidance to obtain fish samples should be retained.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities

Justification/Discussion: Fish and other aquatic biota may populate bodies of water within and beyond the proposed site boundary. The distribution of soluble contaminants in rivers and streams can extend for several kilometers (Muscatello and Janz 2009; Peterson et al. 2002; Havlik et al. 1968a and 1968b). On the other hand, insoluble compounds have limited distribution ranges (NRC 2001b) and may accumulate in locations where the flow of water is limited or precipitates to the bottom sediment (Winde 2002). Additionally, the distribution of contaminants in streams and rivers is downstream to the flow of water (Peterson et al. 2002).

Bodies of water located near or within the proposed boundary of uranium recovery facilities may contain sufficient nutrients to support fish populations and other aquatic biota adequate for seasonal game fishing and, thus, consumption. As it is the case for livestock, game, and garden vegetables, consumption of contaminated fish is a secondary pathway for the intake of radiological contaminants.

3.1.3.5. Soil Samples

Current Guidance

Section 2.1.5 of the current guidance states the following for the operational monitoring of soil samples:

> *Surface-soil samples should be collected annually using a consistent technique at each of the locations chosen for air particulate samples as described in Section 2.1.2.*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the operational monitoring of soil samples described in RG 4.14.

A. **Recommendation:** Licensees should continue to collect soil samples annually, using a consistent technique, at each of the locations chosen for air particulate samples, as specified in the current guidance.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Radiological contaminants are predominantly dispersed via air and water sources. Multiple literature citations exist to document that airborne contaminants are directly deposited onto nearby vegetation and surface soils (examples include Marple 1980; Dreesen et al. 1982; Soudek et al. 2004; Carvalho et al. 2007; Cerne et al. 2010), while those dispersed via water transport are commonly absorbed in nearby soils. However, IAEA 2002 states that contamination of soil (and sediment) media tends to be a slow process and does not result in rapid changes in contaminant concentrations. Therefore, per the IAEA, annual sampling is adequate until additional information is gained on the site-specific transport of soil contaminants (IAEA 2002).

B. **Recommendation:** Given the nature of uranium recovery operations at ISR facilities, additional or alternative soil sample locations should be collected in the areas where recovery operations are conducted.

Applicability: This recommendation is applicable to ISR facilities.

Justification/Discussion: Due to the design, layout, and technology of modern ISR facilities, additional or alternative soil sample locations should be collected to characterize the radiological background. For example, potential releases of radioactivity may occur due to liquid leaks and spills (NUREG-1910 Vol. 1, NRC 2009b). Additional sampling at the location of the proposed wellfields may also be necessary to assess the transport of contaminants in soil.

C. **Recommendation:** Licensees should conduct gamma radiation scans at the preoperational grid transects at least every 5 years during the operational phase.

Applicability: This recommendation is applicable to ISR facilities.

Justification/Discussion: Gamma radiation scans of the preoperational grid transects (see Figure 3-7) should be routinely performed at least every five years during the operational phase to evaluate potential buildup of radioactive contaminants in soil. Judgmental (biased) samples should be taken at any anomalous locations that were not present preoperationally. These data can then be compared over time and provide early indications of potential developing trends or problems at the site due to changing conditions (e.g., spills or ISR wellfield production). Direct comparison of these routine data sets could of course be impacted by changes in instrumentation sensitivity or procedures that may occur between monitoring events. These scans are not intended to supersede the site's established ISR spill program. If routine scanning becomes an area of emphasis, a reduction in the number of required samples may be requested by the applicant.

Licensees should use scanning techniques and equipment that is consistent with preoperational scanning activities.

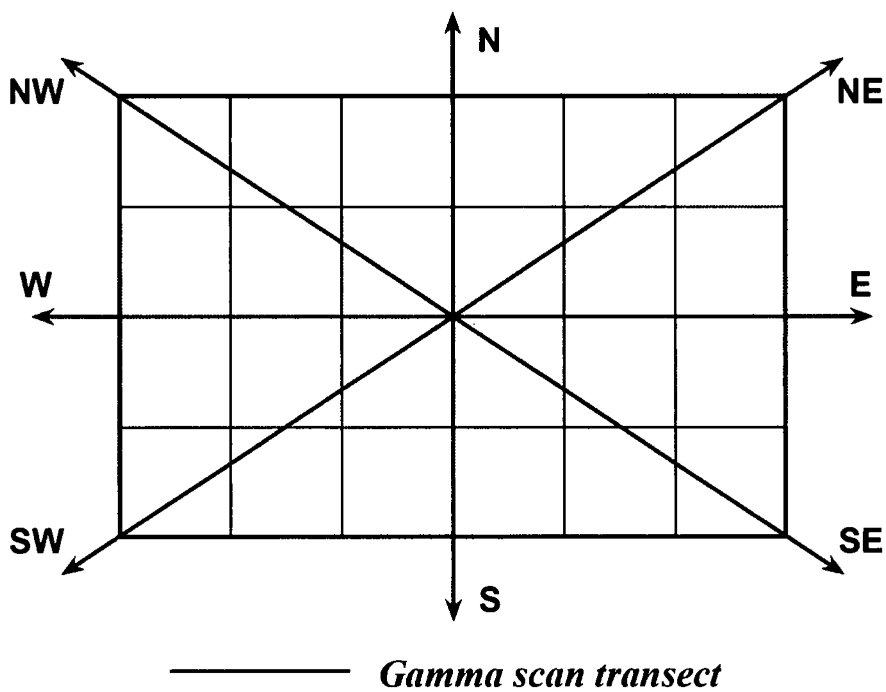


Figure 3-7. Recommended Cartesian Grid with Gamma Scan Transects

3.1.3.6. Sediment Samples

Section 2.1.5 of the current guidance states the following for the operational monitoring of sediment:

> *Sediment samples should be collected annually from the surface-water locations described in Section 2.1.3.*

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justification are provided to enhance the operational monitoring of sediment samples described in RG 4.14.

A. **Recommendation:** Licensees should continue to collect sediment samples annually from the surface water locations, as specified in the current guidance.

   Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

   Justification/Discussion: Radiological contaminants are predominantly dispersed via air and water sources. Multiple literature citations (e.g., Marple 1980; Carvalho et. al. 2007) exist to document that airborne contaminants are directly deposited onto nearby vegetation and surface soils, while those dispersed via water transport are commonly absorbed in nearby sediments (and soil). However, IAEA 2002 states that contamination of sediment (and soil) media tends to be a slow process and does not result in rapid changes in contaminant concentrations. Therefore, annual sampling is adequate until additional information is gained on the site-specific transport of sediment contaminants (IAEA 2002).

3.1.3.7. Direct Radiation

Current Guidance

Section 2.1.6 of the current guidance states the following for the operational monitoring of direct radiation levels:

> *Gamma exposure rates should be measured quarterly at the sites chosen for air particulate samples as described in Section 2.1.2. Passive integrating devices (such as thermoluminescent dosimeters), pressurized ionization chambers, or properly calibrated portable survey instruments should be used (see Regulatory Guide 4.13).*

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the operational monitoring of direct radiation cited in RG 4.14.

A. Recommendation: The direct radiation measurements should be performed on a quarterly basis at air monitoring station locations.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: As discussed in Section 3.1.1.6, passive integrating devices are the preferred type of detection mechanism to measure environmental levels of radiation over a period of several months (i.e., quarterly). Furthermore, portable instruments could also be used to measure exposure rates at fixed locations. Scanning techniques using portable instrumentation mounted in mobile vehicles can be used to measure the site conditions and to track trends in the exposure levels as well as monitor the dose to the public and ensure that exposures are maintained ALARA. These measurements may also be coupled with computational mechanisms to evaluate the radiological conditions during normal operating conditions. Increases in environmental exposure levels may serve as an indicator that radioactive material has extended beyond the controlled areas (IAEA 2002).The direct radiation measurements should be performed on a quarterly basis at air monitoring station locations. The measurement technique(s) used during the preoperational phase should be identical to that used in the operational phase to ensure comparability of results. For example, if licensees opted to measure direct radiation using passive monitoring techniques (e.g., TLDs or OSLs) or a combination of fixed and scanning monitoring techniques during the preoperational phase then this practice should continue during the operational phase to maintain compatibility.

B. Recommendation: Licensees should conduct scans at the original grid measurement locations (or a percentage of those locations), as well as in public access areas, at least every five years.

Applicability: This recommendation is applicable to ISR facilities.

Justification/Discussion: Gamma radiation scans of the preoperational grid transects should be routinely performed at least every five years during the operational phase to evaluate potential buildup of radioactive contaminants. Gamma scan transects are shown in Figure 3-6. The collected data can then be compared over time and provide early indications of potential developing trends or problems at the site due to changing conditions (e.g., spills or wellfield production). Direct comparison of these routine data sets could of course be impacted by changes in instrumentation sensitivity or procedures that may occur between monitoring events. These scans are not intended to supersede the site's established ISR spill program.

Licensees should use scanning techniques and equipment that is consistent with preoperational scanning activities.

3.1.3.8. Radon Flux Measurements

Current Guidance

No guidance exists in RG 4.14 for operational radon flux measurements.

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justification are provided regarding radon flux measurements during the operational monitoring phase.

A. Recommendation: Radon flux measurements should continue to be excluded from the future revision of RG 4.14.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Currently, RG 4.14 does not include recommendations to perform radon flux measurement as part of the operational monitoring program. No technical bases have been identified to include radon flux measurements during the operational monitoring phase. However, regulatory requirements and rationale exist to perform radon flux measurements during post-operational activities which are beyond the scope of the current and future revision of RG 4.14. Refer to Recommendation A of Section 3.1.7 for additional justification.

3.1.4. Frequency and Analysis of Operational Samples

The title of this section has been expanded from the current wording in RG 4.14 to include not only the analysis of operational samples, but the frequency associated with the collection of these samples.

Current Guidance

Section 2.2 of the current guidance states the following for the analysis of operational samples:

> *Samples from the yellowcake dryer and packaging stack should be analyzed for natural uranium. Samples should also be analyzed for thorium-230, radium-226, and lead-210 if this data cannot be obtained from other sources such as isotopic analysis of yellowcake product. Samples from other stacks should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.*
>
> *Air particulate samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.*
>
> *Air samples collected for radon should be analyzed for radon-222.*
>
> *The results of analyses of air samples should be used to determine the radionuclide release rates for the stacks and the radionuclide concentrations for the stacks and other sampling locations.*
>
> *Water samples should be analyzed for natural uranium, thorium-230, radium-226, polonium-210, and lead-210.*
>
> *Ground-water samples from sources not expected to be used as drinking water should be analyzed for dissolved radionuclides. Ground-water samples from sources that could be used as drinking water for humans or livestock and all surface-water samples should be analyzed separately for dissolved and suspended radionuclides. These results should be used to determine radionuclide concentrations for ground water and natural bodies of water.*
>
> *All vegetation, food, and fish (edible portion) samples should be analyzed for radium-226 and lead-210.*
>
> *All soil samples should be analyzed for natural uranium, radium-226, and lead-210.*
>
> *All sediment samples should be analyzed for natural uranium, thorium-230, radium-226, and lead-210.*

3.1.4.1. Stack Samples

Recommendation, Applicability and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the frequency and analysis of operational stack samples in RG 4.14.

A. Recommendation: The updated guidance should encourage licensees to determine the method(s) to analyze stack samples and submit the information to NRC.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The EPA in 40 CFR Part 61, Appendix B, Test Method 114, provides a procedure for the analysis of radiological particulates (such as U-nat, Th-230, Ra-226, and Pb-210). Other applicable Test Methods are found in 40 CFR, Part 60 Appendix A, *Test Methods*.

3.1.4.2. Air Samples

Recommendations, Applicability and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the frequency and analysis of operational air samples in RG 4.14.

A. Recommendation: The radiological contaminants should match those specified in the frequency and analysis of preoperational air samples in Section 3.1.2.1.

Applicability: This recommendation is applicable to all uranium recovery facilities

Justification/Discussion: The frequency and analysis of operational airborne sampling program is a continuation of the preoperational program. To maintain consistency between the preoperational and operational air sampling programs, radiological contaminants of interest identified in the preoperational program should be retained for sampling and analysis in the operational program.

B. Recommendation: The updated guidance should include information on the method(s) to analyze the content of airborne radiological contaminants.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Air particulate samples collected during the operational phase should be analyzed to determine if they contain radiological contaminants, as described in Section 3.1.2.1, for the analysis of preoperational samples. The methods used to analyze radiological particulates and the corresponding equipment sensitivity should be equivalent to those used for preoperational monitoring. Discrepancies in the methods and associated sensitivities can lead to data incompatibility between the preoperational and operational monitoring phases. Without equivalent sensitivity it would be difficult to identify a statistically significant shift in conditions early in the operational monitoring phase.

C. Recommendation: The updated guidance should encourage licensee to include information on the method(s) to analyze devices used for radon monitoring.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The analysis of radon monitoring devices should be performed by an approved dosimetry vendor/supplier, as specified for the analysis of preoperational samples in Section 3.1.2.1. Examples of analytical monitoring methods are provided within the preoperational monitoring section of this document but should not be interpreted as requirements. The analysis method should be proposed and a technical basis, if appropriate, submitted for evaluation to the NRC.

3.1.4.3. Water Samples

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the frequency and analysis of water samples in RG 4.14 collected during the operational period.

A. Recommendation: The current guidance should be updated to remove Po-210 and reflect that the operational sampling scheme is equivalent to (defaults to) the preoperational sampling scheme.

Applicability: This recommendation is applicable to all recovery methods.

Justification/Discussion: The current guidance states that "Water samples should be analyzed for natural uranium, thorium-230, radium-226, polonium-210, and lead-210," and "ground-water samples from sources not expected to be used as drinking water should be analyzed for dissolved radionuclides. Ground-water samples from sources that could be used as drinking water for humans or livestock and all surface-water samples should be analyzed separately for dissolved and suspended radionuclides. These results should be used to determine radionuclide concentrations for ground water and natural bodies of water."

The primary reason for monitoring ground water and surface water during the operational period is to detect excursions. Therefore, the hazardous constituents (refer to 10 CFR 40 Appendix A, Criterion 13) and typical water quality indicators (refer to Table 3-2 in Recommendation B in Section 3.2.2) that were chosen for the preoperational monitoring phase are applicable to the operational monitoring phase. It is occasionally appropriate to change water quality indicators during the course of operations. Provisions should be provided in the updated guidance to permit changes if applicable and appropriate notification and technical justification are provided.

For consistency within this document and the preoperational and operational programs, Po-210 is being removed from analysis in water samples. Refer to Section 3.2 for the technical basis to remove Po-210 from further consideration.

3.1.4.4. Vegetation, Food, and Fish Samples

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the frequency and analysis of operational samples of vegetation, food, and fish in RG 4.14.

A. Recommendation: The analysis for Ra-226 and Pb-210 in vegetation, food, and fish (edible portion) should continue per the current guidance.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Ra-226 is of particular interest in environmental monitoring at uranium recovery facilities due to its long half-life and its ability to accumulate in bone. Ra-226 and Pb-210 have been the center of numerous environmental studies in soils, and vegetation, as well as terrestrial and aquatic food sources, and have been used as environmental indicators of contamination due to uranium recovery operations (Ibrahim et al. 1992; Cerne et al. 2010).

3.1.4.5. Soil and Sediment Samples

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the frequency and analysis of operational samples of soil and sediment in RG 4.14.

A. Recommendation: The analysis in the current guidance should continue for radionuclides specified in soil (U-nat, Ra-226, and Pb-210) and sediment (U-nat, Th-230, Ra-226, and Pb-210). Because no changes are recommended, these two media are discussed concurrently.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: As mentioned previously, Ra-226 and Pb-210 have been utilized as environmental indicators of contamination in terrestrial and aquatic ecosystems. Due to the potential of dispersion via wind erosion of stored ore and tailings, natural uranium may also be analyzed to detect the transport of radiological contaminants in soil. This is of particular interest in ISR facilities where the recovery operation occurs within the location of the ore body.

3.1.5. Quality of Samples

Current Guidance

Section 3 of the current guidance states the following:

> *Provisions should be made to ensure that representative samples are obtained by use of proper sampling equipment, proper locations of sampling points, and proper sampling procedures (see bibliography).*
>
> *Air samples may be composited for analysis if (1) they are collected at the same location and (2) they represent a sampling period of one calendar quarter or less. Air samples should not be composited if (1) they represent a sampling period of more than one calendar quarter, (2) they are from different sampling locations, or (3) the samples are to be analyzed for radon-222.*

Samples collected for analysis of radon-222 should be analyzed quickly enough to minimize decay losses.

Samples other than air samples should not be composited.

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the quality of samples section in RG 4.14.

A. **Recommendation:** Applicants or licensees should obtain representative samples for each of the media listed in this guidance in accordance with current regulatory requirements, acceptable industry practices, and approved site-specific plans and procedures.

   Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

   Justification/Discussion: The collection of samples for analysis should be performed in a manner that is consistent and appropriate for the sample matrix to be obtained. Additional protocols should also be observed and implemented to ensure the representativeness of the samples to the site conditions at the time of sampling, as well as their overall quality before, during, and after sampling and analysis.

   To ensure that adequate quality standards are followed, EPA developed a protocol to provide consistency and guidance when designing sampling plans, collecting samples, as well as conducting analytical measurements and data analysis (EPA 2006), by adopting the data quality objectives (DQO) process. The DQO process is iterative and flexible. It is intended to establish performance and acceptance criteria to support the goals of the site-specific sample plan and to ensure that data of sufficient quality and quantity is collected. Implementing the DQO process is not mandatory; however, it is widely accepted in commercial applications and within the regulatory framework (NRC 2000, MARSSIM; NRC 2004, MARLAP; NRC 2009d, MARSAME; NRC 2009b; EPA 2002b).

   The NRC developed RG 4.15 (NRC 2007) to form the basis of the quality assurance (QA) aspects for radiological monitoring programs of effluent streams and the environment.

The only recommended edit for the future RG is to exclude the parenthetical phrase "(see bibliography)" from language in the current RG 4.14.

B. Recommendation: Airborne particulate samples may be composited (e.g., batched) for analysis based on sample representativeness, sampling location, and monitoring period.

Applicability: This "no change" recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Airborne particulate monitoring should be performed at the locations and for the monitoring periods recommended in Chapter 3 of the TBD. Due to the ambient conditions at uranium recovery facilities, air filters used for the monitoring of particulates could be replaced at predetermined collection periods (e.g., weekly, biweekly) within the recommended monitoring period (i.e., quarterly) to minimize dust loading on the surface of the filters. This will result in the collection of multiple airborne particulate samples within a single monitoring period. Due to the long half-lives of the nuclides in the uranium progeny, particulate filters could be composited (e.g., batched) for analysis based on their sampling location and monitoring period. The increased air volume from the composition of particulate airborne samples will result in lower MDCs for the contaminants of interest.

Airborne particulate samples collected at different sampling locations should not be composited as they are not representative of a single location.

C. Recommendation: Samples of soil, vegetation/foliage, food, and water samples may be composited by location to estimate the mean concentration of the contaminant of interest and to collect sufficient sample mass or volume to meet the DQOs and measurement quality objectives (MQOs).

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Radionuclides with low MDCs may require a large sample mass or volume to meet the sampling DQOs and MQOs for a given measurement method (measurement instrument and protocol) and to adequately measure the radionuclide concentration in the media of interest. Composite sampling may provide a mechanism to obtain sufficient sample mass or volume to meet DQOs and MQOs criteria and assess the contamination levels in the media of interest. Additionally, samples may be composited from multiple sampling points to account for spatial variability when the mean value of the concentration is of interest (useful for direct comparison with ALARA, administrative and/or regulatory limits, or for dose estimation purposes).

During composite sampling, multiple individual samples or subsamples are physically combined and homogenized to form a new sample (i.e., a composite sample) (EPA 2002). Alternatively, a composite sample may be a batch of unblended individual sample units that are tested as a group (Patil 2002). The analyses of interest can then be performed on the composited sample or a subset of the sample obtained from the composite sample. Figure 3-8 (based on Figure 2-6 in EPA 2002a) illustrates the composite sampling process, in which individual samples from several of the selected sampling locations are combined and mixed to form a single homogeneous sample, which is then analyzed. The primary intent of composite sampling is to reduce the number of samples and, thus, the associated costs of analysis, particularly when hard-to-measure radionuclides that require sophisticated and complex measurement methods are present. However, the cost of handling and compositing the individual samples must be taken into account prior to implementation. Composite sampling is typically performed when the handling, compositing, and analytical cost of these samples results in a significant cost reduction when compared to the cost of analyzing individual samples.

Due to the nature of composite sampling, several assumptions apply (EPA 2002a):

- If the concentration of the contaminant of interest can be accurately measured in both the individual and composite samples, then its concentration in the composite should be expected to be the average of the individual measurements (assuming no measurement errors and that the composite protocol is carried properly);
- The variability of the contaminant of interest in the composite samples is less than that of the individual samples; and
- Composite sampling is compatible with the goal of estimating the population mean only.

If these assumptions cannot be met, then composite sampling will not be possible. Additionally, the applicant/licensee must ensure the compatibility of the samples prior to compositing them as incompatibility may introduce significant errors into the sample analyses and results due to weighting or homogenizing activities (EPA 2002a).

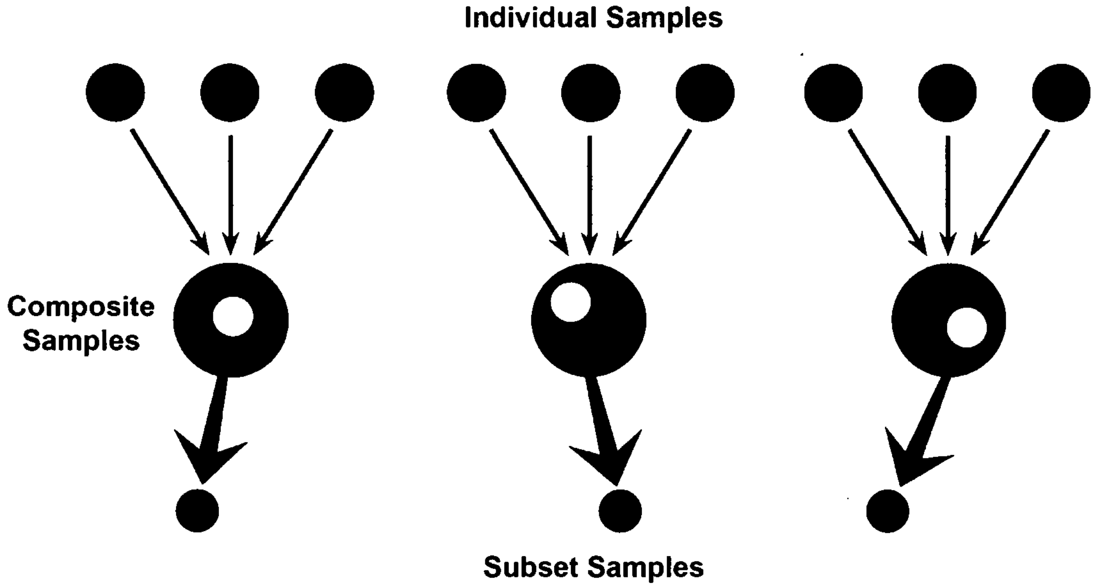


Figure 3-8. Composite Sampling Process

At uranium recovery facilities, media samples (i.e., soil, sediment, water, biota, and vegetation/foliage) are collected to assess the distribution of contaminants, their mobility over time, and potential hazards (e.g., dose) to the environment, biota, and humans. The number of samples and sampling frequency varies according to media type. The sample mass or volume needed to meet the MQOs and DQOs can be collected from several locations within a sampling area to promote adequate representation of the sampling media. For example, an applicant/licensee may collect vegetation/foliage samples from multiple locations within a specified sampling area. Subsequently, the applicant/licensee may composite the vegetation/foliage samples for analyses to determine the radionuclide contaminants and their mean concentration in the sampling area.

The samples can be obtained from random or grid patterns. If a grid pattern is used, then block units that represent a particular area can be designated. The samples obtained from each block unit can be composited for analyses. This approach promotes the expansion of the total sampling area in order to increase the sample coverage in large areas (e.g., ISR wellfields) while maintaining the samples for analyses and their associated costs to a minimum.

Although compositing samples provides a mechanism to minimize the number of samples that need analysis, and their cost, it does present unique implementation challenges. The media that is intended to be composited must be compatible. That is, the samples must be obtained from the same media using identical sampling protocols and the media must present similar physical and chemical characteristics. This may be a limiting factor when compositing soil samples, for example, because the soil composition (i.e., density, grain size, and humidity) could vary greatly within the facility boundary and adjacent areas. Additionally, when the parameter of interest is the mean value of the contaminant concentration (e.g., average radionuclide concentrations in soil, vegetation, food, and water) the individual samples that constitute the composite sample should be of equal mass or volume in order to represent the entire target sampling population. A bias may be introduced to the contaminant concentration results if the individual samples that constitute the composite sample are not of equal mass or volume.

The results from the analyses of composited samples provide an estimation of the mean of the parameter of interest. If the mean is elevated, additional testing of the individual samples may assist in determining the source of the elevation (EPA 2002a and Patil 2002). For example, if the analytical results of a composite sample or a subset of that sample exceed an investigation level (determined by the site) or regulatory limit, the applicant/licensee can re-test the individual samples to identify the source of the elevated result. Once the source is identified, the applicant/licensee can investigate further, commence monitoring, or increase the monitoring frequency as necessary. It is critical that a modified investigation level is established, and is also critical that the MDC of the procedure be less than the modified investigation level. For additional information on composite sampling refer to ORAU 2012.

D. Recommendation: Radon detectors should be analyzed upon completion of their monitoring period.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Current monitoring practices indicate that radon measurements may be performed using integrating passive devices (e.g., alpha track-etch detectors). In the alpha track-etch detector, the alpha particles emitted in the decay of Rn-222 interact with the detector material to produce a series of tracks in the sensitive material that are proportional to the radon concentration. Due to the recording mechanism, the dose information recorded in the alpha track-etch detector can be retained for a longer period of time (several months or more) prior to analysis without compromising the data. Therefore, decay losses are not an issue using this type of detector. (This is not the case if radon measurements are performed using radon charcoal canisters.) However, careful attention is required to prevent further radiation exposure interactions in the detector subsequent to the monitoring period and prior to analysis. Therefore, if the radon detector analyses are performed by a commercial vendor, the applicant/licensee should prepare the radon detectors for analysis according to the manufacturers' instructions to prevent further exposure to radiation. Likewise, if the analyses are performed by the applicant/licensee, then the applicant/licensee should take the necessary precautions to limit additional exposure of the detectors prior to analysis.

3.1.6. Solubility of Airborne Radioactive Material

Current Guidance

Section 4 of the current guidance states the following:

> *Table II of Appendix B, "Concentration in Air and Water above Natural Background," to 10 CFR Part 20 lists separate values for soluble and insoluble radioactive materials in effluents. In making comparisons between airborne effluent concentrations and the values given in Table II of Appendix B to 10 CFR Part 20, the maximum permissible concentrations for insoluble materials should be used.*

Recommendation, Applicability, and Justifications/Discussions

The following recommendation, applicability, and justifications are provided to enhance the solubility of airborne radioactive material section in RG 4.14.

A. Recommendation: Section 4 should be revised to reflect current NRC regulatory requirements based on international and national guidance recommendations.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The air effluent concentrations in 10 CFR 20, Appendix B, Table 2, are based on the chemical form of the inhaled radionuclide compound for aerosols with an activity median aerodynamic diameter of 1 μm. Prior to the revision of 10 CFR 20 in 1991, the "class" was based on two parameters: insoluble or soluble. In the revision of 10 CFR 20 in 1991, rather than designating compounds as insoluble and soluble, a clearance class designation was developed based on the retention of the chemical compound in the pulmonary region of the lung. For example, radionuclides with biological clearance half-times of less than 10 days were designated as day (D) class; for radionuclides with retentions greater than 10 days, but lower than 100 days, a week (W) class was assigned; and for those compounds with retentions greater than 100 days, a year (Y) class was assigned. When the retention of a specific compound of interest in the body is not known, it is common industry practice to use the most restrictive class as the limiting factor to estimate occupational and public doses due to the inhalation of radioactive compounds and to maintain doses ALARA.

The 10 CFR 20, Appendix B, tables are expected to be revised in the future. However, the concentrations listed in Appendix B, Table 2, should continue to be used until revised concentrations are developed and approved for use.

3.1.7. Lower Limit of Detection

<u>Current Guidance</u>

Section 5 of the current guidance states the following:

The lower limits of detection for stack effluent samples should be 10% of the appropriate concentration limits listed in Table II of Appendix B to 10 CFR Part 20.

The lower limits of detection for analysis of other samples should be as follows:

U-natural, Th-230, Ra-226 in air	–	1×10^{-16} *μCi/mL*
Pb-210 in air	–	2×10^{-15} *μCi/mL*

Rn-222	–	2×10^{-10} $\mu Ci/mL$
U-natural, Th-230, Ra-226 in water	–	2×10^{-10} $\mu Ci/mL$
Po-210 in water	–	1×10^{-9} $\mu Ci/mL$
Pb-210 in water	–	1×10^{-9} $\mu Ci/mL$
U-natural, Th-230, Ra-226, Pb-210 in soil and sediment (dry)	–	2×10^{-7} $\mu Ci/g$
U-natural, Th-230 in vegetation, food, and fish (wet)	–	2×10^{-7} $\mu Ci/kg$
Ra-226 in vegetation, food, and fish (wet)	–	5×10^{-8} $\mu Ci/kg$
Po-210, Pb-210 in vegetation, food, and fish (wet)	–	1×10^{-6} $\mu Ci/kg$

Obviously, if the actual concentrations of radionuclides being sampled are higher than the lower limits of detection indicated above, the sampling and analysis procedures need only be adequate to measure the actual concentrations. In such cases, the standard deviation estimated for random error of the analysis should be no greater than 10% of the measured value.

An acceptable method for calculating lower limits of detection is described in the Appendix of this guide.

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the lower limit of detection section in RG 4.14. Several recommendations are offered to revise the lower limit of detection (LLD) nomenclature, identify the role of MARLAP in MDC determinations, describe the MDC in relationship to 10 CFR 20 (Appendix B, Table 2), relate MDC to ALARA goals, and provide derived and calculational approaches for media other than those provided in Appendix B to 10 CFR 20.

A. Recommendation: The term lower limit of detection (LLD) should be renamed the minimum detectable concentration (MDC).

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The LLDs listed in Section 5 are equivalent to MDC calculations in MARLAP and NUREG/CR-4007 (NRC 1984). The MDC is a measure of the detection capability of an instrument system expressed as a concentration. Due to recent changes in nomenclature, licensees may confuse the term LLD with the critical level, S_C (commonly represented as L_C in multiple texts). MARLAP defines the critical level as the threshold value at which a determination could be made for a sample containing measureable radioactivity above background levels at a specific Type I error, α. However, the minimum detectable net count, S_D, used to calculate the MDC, takes both, the α and Type II errors, β, into account.

Type I and Type II errors are the two types of errors that can be made when making decisions based on statistical tests. In the laboratory context, for example, if the null hypothesis of the statistical test is defined as "the analyte is present in the laboratory sample," a Type I error, α, will lead to the conclusion that the sample contains the analyte when it does not and a Type II error, β, will lead to the conclusion that the sample is analyte-free when it is not (i.e., failure to reject the null hypothesis.)

The MDC is defined as the estimate of the true concentration of contaminant required to give a specified probability, 1-β, that the measured response will be greater than the critical level (NRC 2009d, MARSAME; NRC 2004, MARLAP). The LLD, as defined in the Appendix of RG 4.14, is identical to the MDC when the Type I errors (α) and Type II errors (β) are set at 0.05 or 5% (NRC 1984; NRC 2004, MARLAP). Figure 3-9 illustrates the S_C and minimum detectable net signal, S_D, used in the calculation of the instrument- and contaminant-specific MDC.

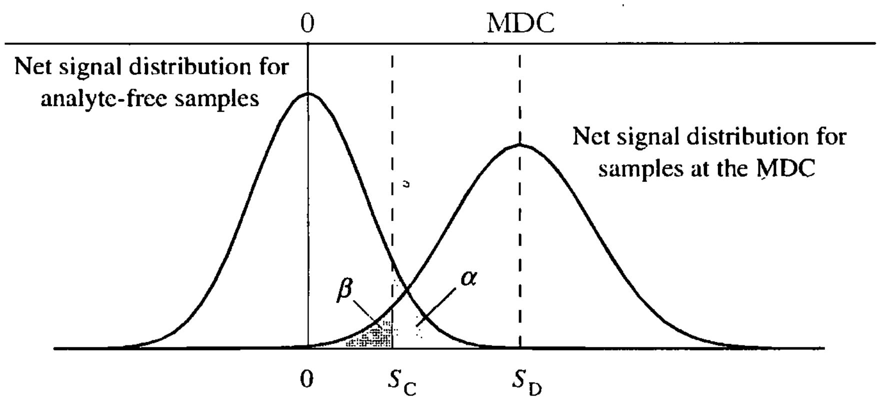


Figure 3-9. Critical Level, S_C, and Minimum Detectable Net Signal, S_D

(NRC 2004, MARLAP)

For decades, it has been common practice to compare analytical results with their corresponding MDC for a particular measurement method (i.e., measurement equipment and technique). However, note in Figure 3-9 that when the contaminant distribution is much greater than the instrument background, the contaminant can be differentiated from the background distribution and can be analyzed and quantified with greater precision. Thus, comparing the analytical results with their MDCs does not affect the decision of whether a sample is contaminant-free or not. On the other hand, when the contaminant distribution is low, as is often the case in environmental samples, the contaminant and background distributions overlap, making it difficult to differentiate the two distributions. Under these conditions, licensees could misidentify non-contaminant free samples as background when their activities are below the MDC but above the S_C.

MARLAP suggests that the MDC be used as a functional characteristic of the measurement method in relation to the contaminant and that the S_C be used for the determination of whether a sample does or does not contain radioactivity above background levels. In other words, the MDC should simply be used as an indication of how capable the measurement method is to identify and/or quantify the contaminant(s) of interest to a predetermined level of uncertainty. Acceptable methods to calculate the S_C and MDC are presented in MARLAP. For illustrative purposes, acceptable methods of calculating the MDC will be presented in the succeeding recommendations.

B. Recommendation: Applicants or licensees should use 10% of the appropriate radionuclide concentration values listed in Table 2 of Appendix B to 10 CFR 20 as the MDC for stack effluent and environmental air and water samples.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The current RG 4.14 recommends that the LLDs (these will be renamed MDCs in the revised RG 4.14) for stack effluent samples should be 10% of the appropriate concentration limits listed in the contemporary Table II of Appendix B to 10 CFR Part 20. This practice should continue but also be extended to include environmental air and water samples, and the 10% values should be drawn from the current Table 2 of Appendix B to 10 CFR 20.

Effluent and environmental monitoring require the use of adequate measurement methods that will allow, with a defined confidence level, the identification and quantification of the contaminant of interest. The MDC is characteristic of the measurement method, sample media, and contaminant; thus, it will vary depending on the selected statistical uncertainties, instrumentation, and measurement protocol. As described in Recommendation A, MARLAP provides guidance to calculate MDC values for analytical measurements. Alternatively, MDC values may be obtained from dose-based standards—listed in 10 CFR 20, Appendix B, Table 2—to ensure that independent of the measurement method selected, an adequate MDC is achieved for each radiological contaminant in air and water. The values listed in 10 CFR 20, Appendix B, Table 2 are nuclide-specific and correspond to the concentrations of radioactive material in air and water that, if inhaled or ingested over a period of a year, would result in a total effective dose equivalent (TEDE) of 50 mrem. Table 3-3 lists several Appendix B radionuclides present at uranium recovery facilities.

RG 8.37 (NRC 1993) is being used as a reference to justify the 10% of Appendix B, Table 2 values. It indicates that based on previous NRC experiences, ALARA goals in the range of 10% to 20% of Appendix B, Table 2 values (or even lower) can be achieved by almost all licensed facilities. Ten percent of Appendix B, Table 2 values would be equivalent to a dose of 5 mrem/yr. Dose-based ALARA goals can also be set to a modest fraction of the dose limit for members of the public. A maximum value of 10 mrem/yr should be practicable for all materials facility licensees (NRC 1993). Furthermore, RG 8.37 states that should 20% of Appendix B, Table 2 values or 10 mrem/yr not be achieved, the licensee may propose equivalent ALARA goals to ensure that the dose limits for members of the public are met.

It is noted that 10 CFR 20, including its appendices, was revised in 1991. This revision incorporated the recommendations presented in International Commission on Radiological Protection (ICRP) Publications 26, *Recommendations of the ICRP*, and ICRP Publication 30, *Limits for Intakes of Radionuclides by Workers* (ICRP 1977 and ICRP 1982, respectively). Furthermore, the Appendix B regulatory limits, annual limits on intake (ALIs), and derived air concentrations for occupational exposure were developed on the basis of the values published in Federal Guidance Report (FGR)-11 (EPA 1988), *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion.* ICRP 30 made modifications to the dose models used previously in 10 CFR 20 from the dose models included in ICRP 2, *Permissible Dose for Internal Radiation*, and ICRP 6, *Recommendations of the ICRP*, (ICRP 1959 and 1964, respectively). Revised Appendix B values based on updated dosimetry information are anticipated. Until these values become available, the current values in Part 20 should continue to be used.

Table 3-3. Recommended Minimum Detectable Concentrations for Analysis of Radiological Contaminants in Air and Water

Environmental Pathway	Radiological Contaminant	Current RG 4.14 MDC (µCi/mL)	Recommended MDC (µCi/mL)[1]
Air	U-nat	1×10^{-16}	3×10^{-13} (Class D)
			9×10^{-14} (Class W)
			9×10^{-15} (Class Y)
	Th-230	1×10^{-16}	2×10^{-15} (Class W)
			3×10^{-15} (Class Y)
	Ra-226	1×10^{-16}	9×10^{-14}
	Pb-210	2×10^{-15}	6×10^{-14}
	Rn-222	2×10^{-10}	1×10^{-9} (excludes progeny)[2]
			1×10^{-10} (includes progeny)[2]
Water	U-nat	2×10^{-10}	3×10^{-8}
	Th-230	2×10^{-10}	1×10^{-8}
	Ra-226[3]	2×10^{-10}	5×10^{-10}
	Pb-210	1×10^{-9}	1×10^{-9}

[1] The recommended MDCs in this table are based on 10% of 10 CFR 20, Appendix B, Table 2 values (with the exception of Rn-222).

[2] The recommended MDC for Rn-222 is equal to the effluent concentration value listed in 10 CFR 20, Appendix B, Table 2. Due to the limitations of current technology, 10% of the value listed in 10 CFR 20, Appendix B, Table 2 is not recommended as the MDC for Rn-222. The MDC for alpha track-etch passive detectors is approximately 8.2 $\times 10^{-11}$ µCi/mL based on a 12-month sampling period. The NRC relayed to ORAU during the preparation of the TBD that radon guidance is being developed (no specific completion or issue dates have been provided). The guidance is expected to specify that the dose from radon should include radon progeny. The revised RG 4.14 will incorporate the NRC's guidance on radon its progeny.

[3] The recommended MDC for Ra-226 is based on 10% of 5 pCi/L as stated in 10 CFR 40, Appendix A, Criteria 5C, *Maximum Values for Ground-Water Protection*, for the operational period of the recovery facility.

C. Recommendation: Licensees should be provided alternative methods to calculate MDCs.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Recommendation B provides MDCs for air and water only based on Appendix B, Table 2. Alternative methods to calculate MDCs may be used for all environmental media.

The MDC calculation has been a topic of discussion for decades (Curie 1968; Brodsky, A. 1993; Strom and Stansbury 1992; NRC 2004, MARLAP; NRC 2009d, MARSAME); thus, variations of the computational method proposed to obtain MDCs vary between authors and selection of input parameters. However, adequate methods to obtain lab-based MDCs have been recently established (MARLAP, MARSAME). These methods allow the licensees to estimate MDCs for analytical assessments of all environmental media without biased assumptions of the measurement parameters.

The MARLAP approach utilizes the "critical net signal" (i.e., critical level, S_C) to estimate the "minimum detectable value of the net instrument signal," S_D, and eventually the corresponding MDC. No single approach exists to estimate S_C. The approach utilized depends on the distribution of the background sample. Most commonly, environmental samples can be approximated by Poisson-normal distributions. In that sense, for quantitative laboratory analyses, when there are no interferences, the critical level can be calculated in one of two ways:

1. For $N_B < 100$ counts

$$S_c = d\left(\frac{t_S}{t_B} - 1\right) + \frac{z_{1-\alpha}^2}{4}\left(1 + \frac{t_S}{t_B}\right) + z_{1-\alpha}\sqrt{(N_B + d)\frac{t_S}{t_B}\left(1 + \frac{t_S}{t_B}\right)}$$

2. For $N_B \geq 100$ counts

$$S_c = z_{1-\alpha}\sqrt{N_B\frac{t_S}{t_B}\left(1 + \frac{t_S}{t_B}\right)}$$

where:

S_C = critical level, counts

N_B = background counts

t_B = background count time, min

d = the critical value of the net instrument signal parameter in the Stapleton Equation (NRC 2004, MARLAP), normally set at 0.4

t_S = sample count time, min

$Z(1-\alpha)$ = $(1-\alpha)$ quantile of the standard normal distribution associated with Type I errors (see Table 3-4)

$Z(1-\beta)$ = $(1-\beta)$ quantile of the standard normal distribution associated with Type II errors (see Table 3-4)

Table 3-4. Percentiles Represented by Selected Values of α and β (NRC 2000, MARSSIM)[1]

α (OR β)	$Z_{1-\alpha}$ (OR $Z_{1-\beta}$)
0.005	2.576
0.010	2.326
0.015	2.241
0.025	1.960
0.05	1.645
0.10	1.282
0.15	1.036
0.20	0.842
0.25	0.674
0.30	0.524

[1]. The value of α is commonly established by regulatory authorities at 0.05 (though other values may be used).

Once S_C is obtained, the minimum detectable value of the net instrument signal, S_D, can be calculated. S_D is defined as the mean value of the net signal that yields a measurement greater than the S_C with a probability of $1-\beta$. The relationship between S_C and S_D is presented in Figure 3-9. S_D may be obtained as follows:

1. For N_B < 100 counts

$$S_D = \frac{\left(z_{1-\alpha} + z_{1-\beta}\right)^2}{4}\left(1 + \frac{t_S}{t_B}\right) + \left(z_{1-\alpha} + z_{1-\beta}\right)\sqrt{N_B \frac{t_S}{t_B}\left(1 + \frac{t_S}{t_B}\right)}$$

2. For $N_B \geq 100$ counts

$$S_D = S_c + \frac{z_{1-\beta}^2}{2} + z_{1-\beta}\sqrt{\frac{z_{1-\beta}^2}{4} + S_c + N_B \frac{t_S}{t_B}\left(1 + \frac{t_S}{t_B}\right)}$$

where the terms are identical to those utilized in the S_C calculations. Note that when, α=β=**0.05** and $N_B > 100$ counts,

$$S_D = z_{1-\beta}^2 + 2\,S_C = 2.71 + 3.29\sqrt{N_B \frac{t_S}{t_B}\left(1 + \frac{t_S}{t_B}\right)}$$

Once the S_D is obtained using one of these approaches, the MDC can be determined. As an example, the MDC for laboratory analyses can be calculated as follows:

$$MDC = \frac{S_D}{\varepsilon \cdot t_S \cdot Y \cdot q \cdot f \cdot \frac{1}{\lambda\, t_S} e^{-\lambda\, t_d}\left(1 - e^{-\lambda\, t_S}\right) \cdot 2.22 \times 10^6\ {}^{dpm}/_{\mu Ci}}$$

where:

MDC	=	minimum detectable concentration, μCi/kg or μCi/mL
S_D	=	minimum detectable value of the net instrument signal, counts
ε	=	total efficiency, counts/disintegrations
t_S	=	sample count time, min
Y	=	fractional radiochemical yield (when applicable)
q	=	quantity of interest (mass in kg or volume in mL)
f	=	subsampling factor (when applicable), fraction of original sample that is ultimately analyzed
t_d	=	decay time, min
λ	=	decay constant for radionuclide of interest, min^{-1}

Supplementary Information

As previously discussed in Recommendation B of this section, a dose-based approach may be implemented and 10% of the values listed in 10 CFR 20, Appendix B (as summarized in Table 3-3) utilized as MDCs for air and water media.

MDCs for Environmental Media Other than Air and Water

For environmental media other than air and water, alternatives beyond Recommendation C exist to calculate MDCs. These media include soil and sediment, and vegetation, food, and fish. Establishing the MDCs is less intuitive and the calculations may be more complex. Jannick et al. 2000 proposed a risk-based approach for calculating limiting concentrations of radionuclides in environmental media based on the concentration that equates to a total, lifetime, stochastic risk of 1×10^{-6} developed in ICRP Publication 60. This approach takes into account the maximum annual intake for the parameter of interest (e.g., meat, milk, vegetables) and utilizes exposure-to-dose conversion factors for ingestion based on the information provided in FGR-11, Table 2.2, *Exposure-to-Dose Conversion Factors for Ingestion* (EPA 1988), to obtain the TEDE (0.05 mrem/yr) that is equivalent to the 1×10^{-6} lifetime risk limit over an upper bound value of 30 years. Subsequently, the risk-based MDC for the radionuclide of interest is obtained by dividing the 0.05 mrem/yr TEDE by the average annual ingestion (mass or volume) for the quantity of interest, the exposure-to-dose conversion factor, and a unit conversion factor to obtain the MDC in terms of μCi/kilogram (kg) or μCi/mL.

The MDC for environmental media can be calculated via the Jannick, et al. approach as follows:

$$MDC = \frac{0.05\ mrem/yr}{q \cdot CDE_{ingestion} \cdot 3.7 \times 10^{9}\ \frac{mrem/\mu Ci}{Sv/Bq}}$$

where:

q	=	average annual ingestion quantity, mass in kg or volume in mL
$CDE_{ingestion}$	=	committed dose equivalent per unit intake, Sv/Bq, listed in FGR-11, Table 2.2 (EPA 1988)

Additionally, a similar approach used to derive the Table 2 values listed in Appendix B of 10 CFR 20 can be utilized to obtain the concentrations of radioactive materials present in other media of interest (e.g., vegetation, food, fish). The media concentrations were derived by taking the most restrictive occupational stochastic oral ingestion ALI provided in 10 CFR 20, Appendix B, Table 1 and dividing by: the average annual ingestion quantity (q) for the media of interest, a factor of 50 to relate the 5,000 mrem annual occupational dose limit to the 100 mrem limit for members of the public, and a factor of 2 to adjust the occupational values (derived for adults) to other age groups. The calculation of the concentration limit in other media may be obtained using the aforementioned approach as follows:

$$C = \frac{sALI}{q \cdot 100}$$

where:

sALI	=	oral ingestion stochastic ALI for nuclide of interest, µCi, listed in 10 CFR 20, Appendix A, Table 1
q	=	average annual ingestion quantity, kg
100	=	conversion factor to relate the sALI to members of the public

As is the case for 10 CFR 20 Appendix B, Table 2 values, the derived concentration for media other than air and water corresponds to the concentration ingested that would result in the maximum permissible annual TEDE (100 mrem/yr) for members of the public. The appropriate MDCs for the radionuclides of interest in air and water can be obtained utilizing the proposed approach described in Recommendation B of this section, that is, 10% of the appropriate radionuclide concentration value. Table 3-5 summarizes the dose-based MDCs for vegetation, food, and fish sampling media.

Table 3-5. Minimum Detectable Concentrations for Analysis of Radiological Contaminants in Vegetation, Food, and Fish

Environmental Pathway	Radiological Contaminant	Current MDC (μCi/kg)	Calculated MDC[1, 6] (μCi/kg)
Food[2]	U-nat[4]	2×10^{-7}	3×10^{-5}
	Th-230	2×10^{-7}	1×10^{-5}
	Ra-226	5×10^{-8}	8×10^{-6}
	Pb-210	1×10^{-6}	1×10^{-6}
Vegetables[3]	U-nat[4]	2×10^{-7}	6×10^{-5}
	Th-230	2×10^{-7}	3×10^{-5}
	Ra-226	5×10^{-8}	1×10^{-5}
	Pb-210	1×10^{-6}	3×10^{-6}
Fish[4]	U-nat[5]	2×10^{-7}	2×10^{-3}
	Th-230	2×10^{-7}	1×10^{-3}
	Ra-226	5×10^{-8}	6×10^{-4}
	Pb-210	1×10^{-6}	1×10^{-4}

[1]MDCs are derived, dose-based concentrations and do not take into account whether the sample is dry or wet.
[2]The average food intake (577.16 kg/yr) was obtained from the average of food disappearance per capita availability based on the most recent available data (calendar year 2009) in the United States (USDA 2012). The food included 49.31 kg of edible portions of meat (beef, veal, pork, lamb, mutton, chicken, and turkey), 252.47 kg of grains (wheat flour, rye, rice, oats, corn products, and barley) and 275.38 kg of dairy products (milk equivalent).
[3]The average vegetable intake (293.88 kg/yr) was obtained from the total vegetable consumption (fresh and processed), 177.31 kg, and total fruit consumption (fresh and processed), 116.57 kg, per capita availability based on the most recent available data (calendar year 2009) in the United States (USDA 2012).
[4] The average fish intake (7.17 kg/yr) was obtained from the total food disappearance per capita availability of fish and shellfish (edible portions/boneless equivalent) based on the most recent available data (calendar year 2009) in the United States (USDA 2012).
[5] U-nat is not included in FGR-11 (EPA 1988). The recommended MDC was calculated based on the natural yield fraction corresponding to each of the MDCs for U-238 and U-235. U-234 was not included in the calculation.
[6] The recommended MDCs provided here are based on 10% of the TEDE limit (50 mrem/yr) for members of the public.

Unlike food, vegetables, and fish, soil and sediment are not inhaled or ingested directly. The radionuclide deposition in soil and sediment depends on the media-to-media transport of radioactive material via air and/or water and subsequently introduced into the food chain via absorption by crops or animals. Due to the indirect ingestion and inhalation mechanisms, suitable MDCs for soil and sediment should be obtained based on current instrument detection capabilities. Additionally, computer models, such as RESRAD, could be used to estimate the radionuclide concentrations that would yield a TEDE of 50 mrem/yr based on the ingestion and/or inhalation of radioactively contaminated soil and sediment.

Scan MDCs

MDC approaches discussed previously were not tailored to the response of a radiation detector in motion, as would occur during a walkover survey of a land area. Guidance for the calculation of scan MDCs for land areas is provided in NUREG-1507 (NRC 1998b). The NUREG-1507 approach is based on the relationship between the radionuclide contamination concentration in soil and the detector's response. Although the NUREG-1507 approach is particularly used during decommissioning activities, it can be extended to any large land areas or material scan surveys where external exposure is the primary concern (as is the case for external exposures due to radiological contamination in soils). Additionally, even when the scan survey results are recorded in counts (i.e., the instrument response), the collected data can be converted into an appropriate unit of reference for direct comparison with established regulatory limits or guideline values during the preoperational, operational, and post-operational phases specific to uranium recovery facilities.

The NUREG-1507 approach consists of multiple procedural steps:

1) Determine the minimum net source counts detectable by the surveyor minimum detectable count rate ($MDCR_{surveyor}$);
2) Determine the volumetric concentration equivalent to a known/predetermined radionuclide concentration;
3) With the assistance of computer modeling software, such as MicroShield, estimate the detector's response to a modeled radionuclide distribution and concentration;

4) Calculate the detector response in cpm to the corresponding exposure rate based on the intrinsic counts per minute (cpm) to exposure rate efficiency for the gamma energies of the contaminants of concern; and
5) Calculate the scan MDC that corresponds to the minimum detectable exposure rate.

For large land areas, a modified approach to that described in NUREG-1507 has been used for remediation purposes (Farr et al. 2010; Johnson et al. 2006). Farr et al. 2010 and Johnson et al. 2006 utilized an array of sodium iodide detectors mounted on mobile vehicles (all-terrain vehicles) to assess the site radiological composition of large land areas and identify "hot spots" that would require further actions. The end result is a detailed site-specific survey map based on the detector's response. It may be important to note that the paradigm for this does not include the "classic" MARSSIM-based MDC calculation, which is based on the audible response. More recently, this approach has been incorporated into preoperational monitoring at uranium recovery facilities to assess the soil radiological conditions of the licensed area (Whicker et al. 2008). The modified approach assumes that U-nat is in secular equilibrium with its progeny (Ra-226 in particular.) The instruments (e.g., sodium iodide detectors) are positioned at discrete distances from each other to allow scanning at a particular resolution. Another assumption of the modified approach is that the Ra-226 concentration in the soil is homogeneous to a depth of 15 cm. The sodium iodide detectors are cross-calibrated with hand-held pressurized ion chambers in order to use the scan data to extrapolate the exposure rate.

When scan surveys are performed, careful attention must be extended to multiple aspects of this approach. For example, topographic variations in the surfaces of the scanned areas may present variations in the soil-to-detector distances, and thus variations in the location of the dose point. In the same manner, speed controls in the survey vehicle must be observed so that the scan MDC is not adversely affected by the reductions in the modeled observation interval of the detection instruments to an assumed area size of concern. Variations in the soil composition will also affect the gamma rays emitted from the soil surface and the instrument response during scan surveys. Additionally, divergence from the assumed U-nat/Ra-226 secular equilibrium and errors in the cross-calibration procedures may also affect the extrapolated exposure rate.

D. Recommendation: Po-210 and its associated MDC should be removed from consideration in the revised regulatory guidance.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: For consistency with prior recommendations in this document pertaining to the elimination of Po-210 as a radionuclide of interest, Po-210 MDCs associated with all environmental media are eliminated from further discussion as well.

3.1.8. Precision and Accuracy of Results

Current Guidance

Section 6 of the current guidance states the following:

Error Estimates

The random error associated with the analysis of samples should always be calculated. The calculation should take into account all significant random uncertainties, not merely counting error.

If the analyst estimates that systematic errors associated with the analysis are significant relative to the random error, the magnitude of the systematic error should be estimated.

Calibration

Individual written procedures should be prepared and used for specific methods of calibrating all sampling and measuring equipment, including ancillary equipment. The procedures should ensure that the equipment will operate with adequate accuracy and stability over the range of its intended use. Calibration procedures may be compilations of published standard practices, manufacturers' instructions that accompany purchased equipment, or procedures written in-house. Calibration procedures should identify the specific equipment or group of instruments to which the procedures apply.

To the extent possible, calibration of measuring equipment should be performed using radionuclide standards certified by the National Bureau of Standards or standards obtained from suppliers who participate in measurement assurance activities with the National Bureau of Standards (see Regulatory Guide 4.15).

Calibrations should be performed at regular intervals, at least semiannually, or at the manufacturer's suggested interval, whichever is more frequent. Frequency of calibration should be based on the stability of the system. If appropriate, equipment may be calibrated before and after use instead of at arbitrarily scheduled intervals. Equipment should be recalibrated or replaced after any repairs or whenever it is suspected of being out of adjustment, excessively worn, or otherwise damaged and not operating properly. Functional tests, i.e., routine checks performed to demonstrate that a given instrument is in working condition, may be performed using sources that are not certified by the National Bureau of Standards.

Quality of Results

A continuous program should be prepared and implemented for ensuring the quality of results and for keeping random and systematic uncertainties to a minimum. The procedures should ensure that samples and measurements are obtained in a uniform manner and that samples are not changed prior to analysis because of handling or because of their storage environment. Test should be applied to analytical processes, including duplicate analysis of selected effluent samples and periodic cross-check analyses with independent laboratories (see Regulatory Guide 4.15).

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the precision and accuracy of results section in RG 4.14.

A. Recommendation: The combined standard uncertainty of a measurement should be estimated and reported along with its corresponding measurement value.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: The uncertainty of a measurement is a parameter associated with calculations, instruments, measurement methods, and human factors. Measurement uncertainties are an unavoidable consequence of any measurement procedure. The greater the uncertainty of a measured value, the lower the probability that the measured value is accurate.

MARLAP states: "The laboratory should report each measured value with either its combined standard uncertainty or its expanded uncertainty." Estimating the combined standard uncertainty of a measurement can be accomplished by propagating the standard uncertainty of the individual components of the measurement. Based on information provided in NRC RG 4.16 Rev. 2, the overarching goal should be to obtain an overall estimate of the uncertainty of the measurement by evaluating the important contributors to the uncertainty. The combined standard uncertainties may vary depending on the measurement method and instrument capabilities.

MARLAP states that measurement uncertainties may be classified as systematic (i.e., bias) or random. Random uncertainties are associated with the variation of the result (e.g., random nature of radioactive decay) from one measurement to the next. Systematic uncertainties, on the other hand, are related to effects that cause variations in the result (e.g., calibration; sample-to-detector positioning; measurements of weight, volume, time, distance). Other uncertainties associated with human performance should also be considered in the combined standard uncertainty, particularly when scan surveys are performed. Contrary to random uncertainties, systematic uncertainties can be identified and corrected in order to limit their absolute effect on the combined standard uncertainty of the measurement.

The combined standard uncertainty can be estimated mathematically using empirical calculations or via computer software that simplifies the process without compromising the calculation. Uncertainty propagation can be performed fairly easily for simple measurements. However, when multiple measurements are performed or when complex algebraic operations are necessary, computational software (e.g., GUMCalc, ProUCL) may be utilized to propagate the uncertainties from multiple parameters or operations and estimate the combined standard uncertainty of the measurement. MARLAP (NRC 2004) provides several approaches to propagate uncertainties for multiple measurement methods. Licensees should consider all sources that could possibly affect the measurement results when estimating measurement uncertainties.

B. Recommendation: All sampling and measuring equipment should be adequately calibrated prior to use and their operation periodically verified.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: 10 CFR 20.1501(b) states "The licensee shall ensure that instruments and equipment used for quantitative radiation measurements (e.g., dose rate and effluent monitoring) are calibrated periodically for the radiation measured." This requirement is extended further in RG 4.15 (NRC 2007) which states, "All equipment should be operated, calibrated, and maintained in adherence to any applicable standards and methods and as specified in the laboratory's quality manual and standard operating procedures."

The operation and maintenance specifications should be provided by the instrument manufacturer. Additionally, the calibration protocols should ensure that the calibration conditions are similar to those in which the instrument will be utilized and that appropriate National Institute of Standards and Technology (NIST) traceable radioactive sources are used during the calibration activities (NRC 2007). Therefore, the text in the current RG 4.14 citing the National Bureau of Standards is outdated and should be modified in the future revision of RG 4.14 to reference current agency; i.e., NIST.

MARLAP, Chapter 15, *Quantification of Radionuclides*, provides general guidelines for the calibration of instruments. More detailed instrument-specific calibration protocols are provided by ANSI, Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Commission (IEC), International Organization for Standardization, and the NIST:

- ANSI N42.12-1994, *American National Standard Calibration and Usage of Thallium-Activated Sodium Iodide Detector Systems for Assay of Radionuclides*
- ANSI N42.13-2004, *American National Standard Calibration and Usage of "Dose Calibrator" Ionization Chambers for the Assay of Radionuclides*
- ANSI N42.14-1999, *American National Standard for Calibration and Use of Germanium Spectrometers for the Measurement of Gamma-Ray Emission Rates of Radionuclides*
- ANSI N42.31-2003, *American National Standard for Measurement Procedures for Resolution and Efficiency of Wide-Bandgap Semiconductor Detectors of Ionizing Radiation*
- IEEE Std 300™-1988, *IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors*

- IEEE Std 309™-1999/ANSI N42.3-1999, *IEEE Standard Test Procedures and Bases for Geiger-Mueller Counters*
- IEEE Std 325™-1996, *IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors*
- ANSI N42.33-2006, *American National Standard for Portable Radiation Detection Instrumentation for Homeland Security*
- IEC 62327:2006, *Radiation Protection Instrumentation—Hand-held Instruments for the Detection and Identification of Radionuclides and for the Indication of Ambient Dose Equivalent Rate from Photon Radiation*
- ANSI N42.17A-2004, *American National Standard Performance Specifications for Health Physics Instrumentation—Portable Instrumentation for Use in Normal Environmental Conditions*
- ANSI N42.17B-1989, *American National Standard Performance Specifications for Health Physics Instrumentation—Occupational Airborne Radioactivity Monitoring Instrumentation*
- ANSI N42.17C-1989, *American National Standard Performance Specifications for Health Physics Instrumentation—Portable Instrumentation for Use in Extreme Environmental Conditions*
- ANSI N323A-1997, *American National Standard Radiation Protection Instrumentation Test and Calibration—Portable Survey Instruments*
- ANSI N323B-2003, *American National Standard for Radiation Protection Instrumentation Test and Calibration—Portable Survey Instrumentation for Near Background Operation*
- IEC 60395:1972, *Portable X or Gamma Radiation Exposure Rate Meters and Monitors for Use in Radiological Protection*
- NIST SP 250-98 ED, *NIST Calibration Services User's Guide, 1998 Edition*

If the instrument calibration is performed by commercial vendors, it is the responsibility of the licensee to ensure that adequate calibration procedures are used. In the same manner, if the calibration activities are performed "in-house," the licensee should develop calibration and quality assurance procedures to ensure that the calibration is performed in accordance with the guidance contained in the aforementioned standards.

The calibration frequency may depend on the licensee's programmatic activities. Radiation instrumentation used to measure radiation and dose levels should be calibrated, at least annually (ANSI N323A 1997). Instrumentation utilized for quantification and analytical procedures may be calibrated more frequently (e.g., semi-annually or as instructed by the manufacturer) to ensure that operational and laboratory specifications are met (NRC 2007). Additionally, RG 4.15, MARLAP, and the specific aforementioned standards indicate that periodic quality control verifications should be performed to ensure the instrument-specific operation is adequate. Contrary to the calibration requirements, quality control verifications do not require NIST-traceable sources. However, the radioactive sources used for quality control verifications should be suitable to ensure reproducibility and provide similar radiological conditions (e.g., emission type and energy) as those intended to be measured.

As is the case for radiological instrumentation, RG 4.15 and MARLAP indicate that instrumentation used for non-radiological measurement and analyses should also be maintained, operated, and calibrated in a manner that is adequate and meets QA standards, site-specific QA programs, procedures, as well as regulatory requirements and guidance.

C. Recommendation: The overall quality of the results should be preserved by licensee site-specific QA programs, procedures, and protocols.

Applicability: This recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: RG 4.15 (NRC 2007) states that QA is fundamentally expected for the items and activities intended for the protection of the public and the environment. Moreover, RG 4.15 emphasizes that the verification and validation of certain aspects and supporting activities of environmental monitoring programs are essential portions of a well-rounded QA program. However, environmental compliance with regulatory limits is based on the comparison of monitoring data for the media of interest against predetermined regulatory limits (e.g., activity, concentration, and/or dose). Therefore, a great degree of effort should be employed to ensure that the samples are representative of the environmental conditions and that their analytical results are of sufficient quality (i.e., meet the DQOs and MQOs) to support the decision-making process. For this purpose MARLAP goes beyond RG 4.15 and recommends the use of the Data Quality Assessment (DQA) process to support the use of technically defensible data.

The DQA (EPA 2000) is an iterative process (similar to the DQO) that follows the data verification and validation processes, but precedes the use of the data. It is applied at a graded approach tailored to the site-specific conditions and the degree of complexity of the processes involved. The DQA is intended to, based on the steps provided below, provide solutions to three basic questions about the results: (1) Are samples representative?; (2) Are the data accurate?; and (3) Can a decision be made?

The DQA consists of the following steps (EPA 2006):

a. Review the monitoring design and data collection for consistency with the program-specific DQOs.

b. Review the results validation to obtain useful statistical information about the collected data.

c. Select the appropriate statistical methods for analyzing the results.

d. Evaluate the assumptions used for the analysis of the results and their applicability.

e. Perform the statistical tests and draw conclusions from the results.

3.1.9 Recording and Reporting of Results

<u>Current Guidance</u>

Section 7 of the current guidance states the following:

> ***Sampling and Analysis Results***
>
> *Air and Stack Samples*
>
> *For each air or stack sample, the following should be recorded:*
>
> 1. *Location of sample.*
>
> 2. *Dates during which sample was collected.*

3. *The concentrations of natural uranium, thorium-230, radium-226, lead-210, and radon-222 for all samples except stack samples.*

4. *The concentration of natural uranium, thorium230, radium-226, and lead-210 for stack effluent samples.*

5. *The percentage of the appropriate concentration limit as shown in Table II of Appendix B to 10 CFR Part 20.*

6. *The estimated release rate of natural uranium, thorium-230, radium-226, and lead-210 for stack effluent samples.*

7. *The flow rate of each stack.*

Liquid Samples

For each liquid sample, the following should be recorded:

1. *Location of sample.*
2. *Type of sample (ground or surface water).*
3. *Date of sample collection.*
4. *The concentrations of natural uranium, thorium-230, radium-226, polonium-210, and lead-210. (If separate analyses were conducted for dissolved and suspended radionuclides, report each result separately).*

Other Samples

For other samples, the following should be recorded:

1. *Location of sample.*
2. *Date of sample collection.*
3. *Type of sample (vegetation, soil, radon-222 flux, gamma exposure rate, etc.).*
4. *Analytical result (radionuclide concentration, gamma exposure rate, radon flux rate, etc.).*

Error Estimates

Reported results should always include estimates of uncertainty. The magnitude of the random error of the analysis to the 95% uncertainty level should be reported for each result. If significant, an estimate of the magnitude of the systematic error should also be reported.

Supplemental Information

The following information should be included in each monitoring report submitted to NRC:

1. *Name of facility, location, docket number, and license number.*
2. *Description of sampling equipment and discussion of how sampling locations were chosen.*
3. *Description of sampling procedures, including sampling times, rates, and volumes.*
4. *Description of analytical procedures.*
5. *Description of calculational methods.*
6. *Discussion of random and systematic error estimates, including methods of calculation and sources of systematic error.*
7. *The values of the lower limits of detection, along with a description of the calculation of the lower limit of detection.*
8. *The values of maximum permissible concentration from Table II of Appendix B to 10 CFR Part 20 used in any calculations.*
9. *Discussion of the program for ensuring the quality of results.*
10. *Description of calibration procedures.*
11. *Discussion of any unusual releases, including the circumstances of the release and any data available on the quantities of radionuclides released.*

Units

Radionuclide quantities should be reported in curies. Radionuclide concentrations should be reported in microcuries per milliliter for air and water, microcuries per gram for soil and sediment, and microcuries per kilogram for vegetation, food, or fish. Direct radiation exposure rates should be reported in milliroentgens per calendar quarter.

Radon flux rates should be reported in picocuries per square meter per second. Stack flow rates should be reported in cubic meters per second. (In the International System of Units, a curie equals 3.7×10^{10} becquerels, a microcurie equals 3.7×10^{4} becquerels, and a milliliter equals 10^{-6} cubic meters).

Estimates of random error should be reported in the same units as the result itself. Estimates of systematic error should be reported as a percentage of the result.

Note: The Commission has discontinued the use in 10 CFR Part 20 of the special curie definitions for natural uranium and natural thorium (39 FR 23990, June 28, 1974). Reports to the Commission should use units consistent with this change.

Significant Figures

Results should not be reported with excessive significant figures, so that they appear more certain than they actually are. The reported estimate of error should contain no more than two significant figures. The reported result itself should have the same number of decimal places as the reported error.

Format

Reports should be submitted according to the format shown in Table 3.

The term "not detected," "less than the lower limit of detection (LLD)," or similar terms should never be used. Each reported result should be a value and its associated error estimate, including values less than the lower limit of detection or less than zero.

Recommendations, Applicability, and Justifications/Discussions

The following recommendations, applicability, and justifications are provided to enhance the recording and reporting results section in RG 4.14 and provide supplemental guidance to meet the reporting requirements established in 10 CFR 40.65.

A. Recommendation: Applicants or licensees should report analytical results with sufficient sample information to readily identify the sample, sampling location, environmental conditions at the time of collection, associated uncertainties, and their relationship to regulatory limits.

Applicability: The recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Sample identification, data recording, and data reporting are an integral part of a comprehensive quality assurance program. Although the level of rigor of environmental monitoring programs at licensed facilities is site-specific, RG 4.15 (NRC 2007) and MARLAP provide the level of sample identification and data reporting that is expected for radiological environmental monitoring programs.

Proper identification of samples is necessary to associate the analytical result with a specific sampling location, environmental conditions, and point in time. Additionally, the level of identification should be sufficient to provide all necessary information for further assessment of the analytical data. It is common practice to assign unique identifiers to analytical samples in order to ease sample management, via chain-of-custody, and data reporting.

As recommended in MARLAP (NRC 2004), Table 16-2, data packages may also be developed for each unique identifier or group of samples. The data packages may assist the licensees with sample management, analysis processes, data management, and subsequent quarterly reports. An example of an acceptable reporting format is provided in the appendices of this document.

B. Recommendation: Records should be properly maintained and readily available.

Applicability: The recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: 10 CFR 20.2107 states: "(a) Each licensee shall maintain records sufficient to demonstrate compliance with the dose limit for individual members of the public. (b) The licensee shall retain the records required by paragraph (a) of this section until the Commission terminates each pertinent license requiring the record."

RG 4.15 (NRC 2007) provides guidance for the type of documentation that should be maintained, as well as the conditions for controlling those records. Current technological advances allow for records to be maintained electronically with limited risk of getting lost, damaged, or compromised. Electronic record storage should be, whenever possible, utilized in conjunction with physical controls.

C. Recommendation: Measurement uncertainties should be estimated, recorded, and reported in accordance with established DQOs and MQOs.

Applicability: The recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Measurement uncertainties at uranium recovery facilities should be estimated, recorded, and reported by licensees. Uncertainties primarily include those tied to the measurement or counting of radioactive samples. Recommendation A in Section 3.8, *Precision and Accuracy of Results*, describes a combined standard uncertainty which can be significant if all possible uncertainties associated with a result are determined and calculated. The information provided in Recommendation A should be consulted for applicable details.

D. **Recommendation:** All results should be presented in units that are appropriate for the measured/analyzed parameter.

Applicability: The recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: Results of radiological and non-radiological measurements should use appropriate units. In RG 4.14 radiological units are associated with stack, air, water, vegetation, food, fish, soil, sediment, and direct radiation measurements. The NRC in 10 CFR 20 cites radiological units in both traditional units (e.g., Ci, pCi, mrem) and the International System of Units (SI) (e.g., becquerels, sieverts). Licensees should discuss with NRC the selection of acceptable reporting units. Clear distinctions should be made between the two unit systems. For example, if traditional units are selected for reporting, SI units should be presented in parentheses per NRC's standard practice in 10 CFR 20.

Radon flux units should be excluded from the revised RG 4.14 since radon flux measurements will be excluded from the guide.

The revised RG 4.14 will recommend non-radiological monitoring for water and the non-radiological units for the results should be expressed in appropriate reporting units. These include units such as: mg/L, and conductivity (expressed in micromhos/cm).

Estimated uncertainties should be reported in the same units as the measurement result.

E. **Recommendation:** All results should be reported to the number of significant figures warranted by the uncertainty approximation or as required by the NRC.

Applicability: The recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: All results should be reported as obtained and accompanied by their corresponding uncertainty (MARLAP). The number of significant figures included in the reporting of the results depends on the uncertainty associated with the result. The results should be no more precise than the most precise parameter that is included in the overall uncertainty. In the same manner, MARLAP indicates that environmental radiation measurements could warrant the use of more than two or three significant figures for the reported value and that the corresponding uncertainty should be no more than two significant figures. Moreover, the result should be rounded to the same number of decimal places as its uncertainty. For example, a value of 0.752412 pCi/mL with an associated uncertainty of 0.0234 pCi/mL should be reported as 0.752 ± 0.023 pCi/mL.

It is important to stress that rounding should only be performed when reporting the final result. Any rounding during intermediate calculations will introduce round-off errors (NRC 2004, MARLAP).

F. **Recommendation:** The report formatting should follow the generic example provided in Appendix D of this document for radiological data.

Applicability: The recommendation is applicable to all uranium recovery facilities.

Justification/Discussion: There is no single approach for reporting monitoring results. However, to ease the review of environmental monitoring reports, an example is provided in Appendix D that is applicable to all uranium recovery facilities. This generic example can be modified as necessary to meet facility-specific reporting requirements. The example includes all the monitoring media recommended for monitoring in this document. Additionally, the report example can be utilized for the preoperational and operational quarterly reports.

All reportable results should be presented as measured or determined (NRC 2004, MARLAP). All values, negative and positive, affect the distribution of the data, and thus should be reported. Not reporting negative values or assigning zero to negative values will bias the data towards higher values and may guide the licensees, and NRC, to false conclusions (this is particularly important when the mean value is directly compared to a regulatory limit). The results may be compared with the critical value to identify radiologically-contaminated materials. Withholding the reporting of negative values will also introduce unwanted uncertainties to the overall results used for decision making. An uncertainty should accompany every measured or determined value as previously described in Recommendation E of this section.

4. LAND USE CENSUS

Land use is one of the local site characteristics that should be examined in order to evaluate the pathways that can potentially contribute to the dose to any individual as a result of any site activity. A land use census is an assessment of the local characteristics of the site and its vicinity that includes present and anticipated future uses of the land; for instance, agriculture, livestock raising, dairies, pasturelands, residences, wildlife preserves, sanctuaries, hunting areas, industries, recreation, and transportation.

The current RG 4.14 does not include guidance for conducting a land use census at uranium recovery facility surroundings. Therefore, the revision to RG 4.14 should be expanded to include information on how to conduct a land use census at each type of uranium recovery facility to identify changes in land use, receptors, receptor locations, and new exposure pathways. The land use census information can be used to provide the basis for making necessary modifications to the environmental monitoring program at uranium recovery facilities.

This chapter provides recommendations on how to conduct a land use census. Additional guidance for conducting a land use census can be found in RG 4.1 (NRC 2009a) and NUREG-1301/1302 (NRC 1991a, 1991b). Furthermore, RG 3.46 (NRC 1982a), RG 3.8 (NRC 1982b), and NUREG-1748 (NRC 2003b) contain information on how to incorporate land use and census data into a site environmental report. This environmental report is required to be submitted with the license application per 10 CFR Part 51. The land use census should be conducted and reported annually as part of the environmental report for the site.

4.1. METHOD FOR CONDUCTING A LAND USE CENSUS

To conduct a land use census, the nature and the extent of the current and projected land use and any recent trends such as major or unexpected changes in population or industrial patterns should be indicated within an 8-km (5-mi) radius.

The land census should indicate within a distance of 8 km (5 mi) from the center of the site, the locations—in each of the 22.5 degree sectors centered on the 16 cardinal compass points—of the following land uses:

- The nearest cattle or other meat animals grazing on natural forage, with types and numbers of animals specified
- The nearest game animals consumed by sportsmen
- The nearest residence
- The nearest site boundary
- The nearest recreational areas
- The nearest garden greater than 50 m^2 (500 ft^2) that yields crops (with the type of crop and amounts produced noted) (NRC 1982b, 1991a)

Where possible, specific information should be provided regarding actual consumption of the meat from cattle and game animals (NRC 1982b, 1991a). Additional information should be provided on grazing season (months of year) and feeding regimens for cattle. Agricultural production, crop yield, grazing, and feeding data may be obtained from sources such as local, state, and federal agricultural agencies, agricultural agents, and other reliable sources (NRC 1982b).

Separate maps of the site and its vicinity should be provided as part of the land use census. The following detailed maps should be included:

- A map to indicate the site and its location with respect to any federal land and to state, county, and other political subdivisions
- A map to indicate the location of the proposed uranium recovery operations, all associated principal structures (e.g., processing plant, evaporation impoundments, tailings disposal areas) and location of wellfields particularly for ISR facilities
- A map of the applicant's property; adjacent properties, including water bodies and farms; nearby settlements; industrial plants, parks, and other public facilities; and transportation links (railroads, roadways, waterways)

- A map to indicate present and anticipated land use within an 8-km (5-mi) radius from the center of the facility—in each of the 22.5 degree sectors centered on the 16 cardinal compass points

- A map of the total acreage owned or leased by the applicant and that part occupied by or which will be modified for the uranium recovery site

- A map to indicate any other existing and proposed uses of applicant's property and the acreage devoted to these uses

- Any plans for site modifications such as a visitors' center should be described. A contour map of the site should also be supplied with elevation contours of an interval suitable to show significant variations of the site environs and drainage gradients. In addition, indicate if the site is in the vicinity of a flood plain.

This information should be supplied as separate maps, if necessary, for clarity (NRC 1982a and NRC 1982b). A web mapping service application (e.g., Google maps) may be used for some of the maps (e.g., to identify the nearest cattle as well as the nearest residence).

4.1.1. Periodic Land Use Census

As a component of environmental monitoring activities, a formal land use census should be conducted annually during the growing and grazing season to identify and evaluate changes in land use, receptor, receptor locations, new pathways, and/or routes of exposure (NRC 2009a).

Although a land use census is recommended on an annual basis, changes in land use should be noted during the performance of routine environmental monitoring activities throughout the year. This should be adopted as a standard practice and changes or no changes in land use should be documented. This will help maintain a record of activities at the site and its vicinity throughout the year. Then a formal land use census can be conducted and reported at the end of the year. It is important to describe and clearly state in the report what was found during the annual land use census even if there were no changes from the previous year.

4.2 IDENTIFICATION OF NEW OR MODIFIED EXPOSURE PATHWAYS OR ROUTES OF EXPOSURES AND SAMPLING LOCATIONS

During or upon completion of the land use census, new or modified exposure pathways or routes of exposure may arise during the preoperational or operational monitoring phase at a facility. These pathways or exposure routes may result from changes in land use near the site, receptor, receptor locations, and/or facility modifications.

4.2.1. Exposure Pathways

Per Till and Grogan (2008), exposure pathways describe the mechanisms or paths by which a person may be exposed to radionuclides in a single environmental medium. For a person to be exposed to a radionuclide, the radionuclide must be present in an environmental medium (e.g., soil, air, vegetation or water) that the person would likely be in contact with during regular activities. As noted by Till and Grogan (2008), for most persons, there will be exposures to multiple radionuclides in multiple environmental media through multiple exposure mechanisms (e.g., inhalation, ingestion, or external radiation). The development of exposure pathways provides a means to document each type of exposure associated with each type of activity for each location of a person (Till and Grogan 2008).

The following components of an exposure pathway are directly excerpted from Till and Grogan (2008):

- *Sources and source areas (e.g., stack emissions, disposal areas) that are identified within the evaluation area.*
- *Radionuclides that are associated with the sources and source areas.*
- *Exposure areas that describe the locations or areas where a person is likely to come in contact with environmental media containing a radionuclide.*
- *Potentially exposed persons who are likely to come in contact with environmental media containing a radionuclide.*
- *Behaviors and activities of potentially exposed persons that describe the daily activities of a person at home, at work, or while recreating.*

- *Exposure media that include air, soil, water, sediment, and other natural materials that a person may come in contact with during daily activities.*

- *Routes or mechanisms of exposure that describe the way in which a person comes in contact with a radionuclide (e.g., inhalation, ingestion, or external radiation).*

- *Transport media (e.g., air, surface water) and mechanisms (e.g., dispersion, diffusion) for a radionuclide to travel or be transported by one or more environmental media from sources or source areas to environmental media in an exposure area.*

- *Transfer mechanisms (e.g., water-to-air volatilization, root uptake) for a radionuclide to transfer from one environmental medium to another environmental medium at a source or source area or in an exposure area.*

Exposure routes or pathways that should be considered at uranium recovery facilities are inhalation, ingestion, and external radiation. Gamma emissions from uranium and its progeny are primarily an external hazard, while the inhalation and ingestion pathways consist of one or more routes of entry into the body.

A route of exposure is a specific path (or delivery mechanism) by which radionuclides, initially in the environment at a specified location, can eventually cause a radiation dose to a person. The path normally includes a type of environmental medium (e.g., air, vegetation, meat, or water) as the starting point and a recipient's organ or body as the end point. Each of these environmental media provides a different route by which radionuclides may be transferred from the environment to an individual (causing an exposure). These routes of exposure are identified based on site-specific information (e.g., receptors, receptor locations, distances, directions, and water usage) identified during the land use census (NRC 2009a).

Considering the three principal exposure routes or pathways that should be evaluated at uranium recovery facilities, only the inhalation pathway exists at every site; the ingestion and external exposure pathways are routes of exposure that may or may not occur at every site.

The topic of pathway analysis can be complicated, but general information related to pathway analysis, including a conceptual site model (CSM), is presented in Appendix E of this document.

4.2.2 Impact on Sampling Locations

If the land census for the site identifies a new pathway or new route of exposure that contributes more than 20% to the calculated individual dose, then the sample media associated with the new pathway or route of exposure should be added to the environmental monitoring program (NRC 1991a, NRC 2009a). The unnecessary sampling locations (sampling locations with the lowest calculated dose) should be maintained until approval is obtained from the NRC to eliminate these locations.

Sampling of vegetation at the site boundary can be performed in lieu of a garden census. A garden census applies to gardens greater than 50 m^2 since this is the minimum garden size required to produce the necessary consumption quantity (26 kg/y) of leafy vegetables that will cause a child to be maximally exposed (NRC 1977 and 1991a).

Sampling of livestock (e.g., cattle, sheep, and other meat animals) may be needed if the land use census reveals that a significant amount of meat is raised locally and an evaluation demonstrates that meat consumption contributes a 20% dose increment to the total individual dose. In the same way, sampling meat from game animals may be necessary if hunting accounts for a significant amount of meat obtained for consumption (NRC 2009d).

The specific type of vegetation or livestock samples should be specified by using the common names. For example, a common name for a plant is "big sagebrush" and a common name for livestock is "cattle." The scientific name (genus/species) may be provided if it is readily available. Generic terms such as vegetation, plant, crops, or livestock should be avoided.

The 20% dose increment to the total individual dose pertains to the increase in dose being received by individual members of the public due to e.g., changes in land use near the site, receptor, receptor locations, and/or facility modifications.

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APPENDIX A

SUMMARY OF RECOMMENDATIONS

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APPENDIX A. SUMMARY OF RECOMMENDATIONS IN CHAPTERS 3 AND 4

PREOPERATIONAL MONITORING GENERAL RECOMMENDATIONS		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.A	All	The words "mining operations" should be changed to "uranium recovery."
3.1.1.B	All	The difference between the terms "background" and "baseline" should be addressed in the future revision of RG 4.14.
3.1.1.C	All	The current guidance should be expanded to include environmental monitoring for non-radiological contaminants in ground water and surface water.
3.1.1.D	All	Applicants should perform a more representative and comprehensive preoperational baseline by continuously monitoring existing onsite background radiological and non-radiological environmental media for a period of two years.
3.1.1.E	All	Table 1 of the current guidance, *Preoperational Radiological Monitoring Program for Uranium Mills*, should be updated to reflect the modifications recommended in this document. Additionally, for ease of reference, separate tables (for each facility) summarizing the preoperational radiological and non-radiological monitoring programs should be included.
3.1.1.F	All	Applicants should continue to propose alternative approaches to the preoperational monitoring program that are equivalent to (compatible with) the operational program.
3.1.1.G	All	Methods to calculate public doses from proposed operations should be determined by the applicants and submitted for evaluation to the NRC. This should be included in the NRC RG 4.14 revision.

[1] This indicates the type of uranium recovery facility that the recommendation is applicable to, e.g., "All" means the recommendation is applicable to the three different types of uranium recovery facilities (conventional mills, in situ and heap leach).

PREOPERATIONAL MONITORING AIR SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.1.A	All	Applicants should evaluate meteorological conditions, using onsite monitoring stations, for at least 12 consecutive months prior to establishing the preoperational air sampling program to support the determination of appropriate air sampling locations.
3.1.1.1.B	All	The number of sampling locations in the current guidance (at least three) should be retained and potentially increased based on the evaluation of meteorological data collected prior to the onset of the preoperational phase.
3.1.1.1.C	Conventional Mills and Heap Leach	The recommendations in the current guidance for the placement of the upwind (background or control) air sampling location should be retained for conventional mills and heap leach facilities; however, the number of upwind locations should not be limited to one.
3.1.1.1.D	ISR	For ISR facilities, applicants should evaluate whether the upwind (background or control) location(s) should be established at the nearest town or population density center that is beyond the influence of the site, preferably in the least prevalent wind direction.
3.1.1.1.E	All	The current guidance stating that "...a continuous outdoor air sample should be collected...at or near at least one structure in any area where predicted doses exceed 5 percent of the standards in 40 CFR Part 190" should be eliminated.
3.1.1.1.F	All	The number of downwind air sampling locations should not be limited to one.
3.1.1.1.G	All	Applicants should be provided flexibility in determining the frequency of replacing air filters.
3.1.1.1.H	All	The language in Table 1 (*Preoperational Radiological Monitoring Program for Uranium Mills*) of the current guidance should be expanded to match the language in Table 2 (*Operational Radiological Monitoring Program for Uranium Mills*) by including the different sectors having the highest predicted concentrations of airborne particulates.

PREOPERATIONAL MONITORING AIR SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.1.I	All	The preoperational monitoring of radon gas concentrations should be performed in additional locations—beyond those that are co-located with the air particulate sampling stations—for two years.
3.1.1.1.J	All	Integrating passive devices (e.g., track-etch detectors) should be employed as the method to measure environmental levels of radon in air and deployed at least quarterly.

PREOPERATIONAL MONITORING WATER SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.2.A	All	The updated regulatory guidance should include a discussion of ground water sampling frequency.
3.1.1.2.B	All	Regarding ground water monitoring and sampling, the current guidance should be strengthened for each specific uranium recovery facility type to provide additional information on the ground water monitoring network, including number and locations of ground water wells and depths of monitoring well screens.
3.1.1.2.C	All	The recommendation in the current guidance for the collection of ground water samples from existing private wells within 2 km of tailings areas that are or could be used for drinking water, watering of livestock, or crop irrigation remains adequate for conventional mill facilities and should be extended to ISR and heap leach facilities. Additionally, this distance should be included for the collection of surface water samples from onsite natural and man-made impoundments.
3.1.1.2.D	All	The current sampling frequency guidance should be modified to "at least quarterly" and be limited to natural or man-made surface water impoundments.

PREOPERATIONAL MONITORING WATER SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.2.E	All	The current guidance regarding monthly sampling, which includes onsite and offsite collection of samples from streams, rivers, and associated areas, should be retained. However, guidance should clarify the number and location of samples.
3.1.1.2.F	All	With respect to flowing surface water bodies, the language in Table 1 (*Preoperational Radiological Monitoring Program for Uranium Mills)* of the current guidance should be expanded to match the language in Table 2 (*Operational Radiological Monitoring Program for Uranium Mills*) by including the establishment of upstream and downstream surface water sampling locations so that consistency is achieved in sample location during the preoperational and operational phases.
3.1.1.2.G	All	Examples of acceptable field sampling methods should be incorporated in the guidance; however, the future RG 4.14 should indicate that the applicant is responsible for choosing, defining, and defending the methods proposed for evaluation to the NRC.

PREOPERATIONAL MONITORING VEGETATION, FOOD, AND FISH SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.3.A	All	The current guidance to obtain forage vegetation samples at the specified locations and frequency should be retained.
3.1.1.3.B	All	The current guidance to obtain crop samples (including those from vegetable gardens) or livestock samples at the specified locations and frequency should be updated to include the option to obtain samples of game animals.

PREOPERATIONAL MONITORING VEGETATION, FOOD, AND FISH SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.3.C	All	The current guidance to obtain fish samples at the specified locations and frequency should be retained.

PREOPERATIONAL MONITORING SOIL SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.4.A	All	The current guidance for preoperational soil sampling locations should be evaluated on a facility-specific basis.
3.1.1.4.B	All	Surface soil sampling depths collected during the preoperational sampling period should be expanded in the revised guidance to include a 15 cm depth consistent with 10 CFR Part 40, Appendix A.

PREOPERATIONAL MONITORING SEDIMENT SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.5.A	All	The current guidance to collect sediment samples at specified locations and frequency should be retained.

PREOPERATIONAL MONITORING DIRECT RADIATION		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.6.A	All	Applicants are encouraged to make use of currently available or newer techniques to perform direct radiation measurements.
3.1.1.6.B	All	The current guidance for performing direct radiation measurements should be evaluated on a facility-specific basis.

PREOPERATIONAL MONITORING RADON FLUX MEASUREMENTS		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.1.7.A	All	Radon flux measurements should be eliminated from the future revision of RG 4.14.

FREQUENCY AND ANALYSIS OF PREOPERATIONAL SAMPLES GENERAL RECOMMENDATION		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.2.A	All	The analysis of Po-210 in all collected media samples should be eliminated from the next revision of RG 4.14.

FREQUENCY AND ANALYSIS OF PREOPERATIONAL SAMPLES AIR SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.2.1.A	All	The revised guidance should retain natural uranium (U-nat), Th-230, Ra-226, and Pb-210 as airborne particulates for analysis purposes.
3.1.2.1.B	All	The current guidance should be updated to include examples of the methods to analyze air samples for radiological particulates and radon; however, the applicant is responsible for choosing, defining, and defending the methods and frequency of analyses proposed for evaluation to the NRC.

FREQUENCY AND ANALYSIS OF PREOPERATIONAL SAMPLES WATER SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.2.2.A	All	The current guidance should be revised to include sampling of both radiological and non-radiological compounds to meet ground water protection standards per 10 CFR 40, Appendix A. (See Recommendation B for non-radiological constituents.)
3.1.2.2.B	All	The current guidance should be updated to include the analysis of non-radiological contaminants associated with the preoperational water sampling program.
3.1.2.2.C	All	While the sampling analysis intervals currently provided in RG 4.14 remain acceptable for conventional uranium mills, applicants should be afforded flexibility to offer alternative time intervals to conduct the analyses for all types of uranium recovery facilities.
3.1.2.2.D	All	The current guidance should be revised to include sampling of both radiological and non-radiological compounds. (See Recommendation E for non-radiological constituents.) The radioanalytical suite for surface water samples should be site-specific and established based on consideration of operational processes and type of uranium recovery facility.

Frequency and Analysis of Preoperational Samples Water Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.2.2.E	All	The current guidance should be updated to include the analysis of non-radiological contaminants for surface water associated with the preoperational water sampling program as applicable to the recovery process and type of facility.

Frequency and Analysis of Preoperational Samples Vegetation, Food, and Fish Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.2.3.A	All	Applicants should continue to analyze for U-nat, Th-230, Ra-226, and Pb-210 in edible vegetation, food, and fish samples but eliminate analysis for Po-210.

Frequency and Analysis of Preoperational Samples Soil and Sediment Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.2.4.A	All	The analysis in the current guidance should continue for radionuclides specified in soil and sediment (U-nat, Th-230, Ra-226, and Pb-210). Because no changes are recommended, these two media are discussed concurrently.

Operational Monitoring General Recommendations		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.A	All	The current guidance to continue environmental monitoring during construction and after the beginning of milling operations should be retained in the upcoming revision of NRC RG 4.14 and expanded to other types of uranium recovery facilities.
3.1.3.B	All	Operational monitoring should include the monitoring of non-radiological contaminants from surface and ground water sources. (This was also recommended for the preoperational monitoring section in this document.)
3.1.3.C	All	The reporting format in Table 3 of the current guidance should be updated to incorporate all types of uranium recovery facilities.
3.1.3.D	All	Based on the recommendations made for the preoperational and subsequently the operational monitoring program, Table 2 of the current guidance is inadequate and should be updated.

Operational Monitoring Stack Sampling		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.1.A	All	The "at least" quarterly sampling frequency cited in the current guidance for effluent emissions from the yellowcake dryer (i.e., gas-fired multihearth dryer) and packaging stack during normal operations should be removed and the language modified to consider newer yellowcake dryer designs (i.e., vacuum dryer).

OPERATIONAL MONITORING STACK SAMPLING		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.1.B	All	The recommendation in the current guidance citing isokinetic, representative and adequate sampling for determination of the release rates and concentrations of uranium should be retained with the exception of isokinetic sampling. However, the language should be modified to acknowledge these conditions may not be satisfied in all cases, i.e., for all facilities using a vacuum dryer. The current language is associated with the use of multihearth dryers for yellowcake.
3.1.3.1.C	ISR	Language should be added that radon is the primary radioactive airborne effluent release at ISR facilities during normal operations.
3.1.3.1.D	All	The current guidance should be updated to include information on the differences between ambient air sampling and stack effluent sampling or the importance of stack monitoring.
3.1.3.1.E	All	The current guidance for sampling stacks other than the yellowcake dryer and packaging stacks at least semiannually and recommending representative and adequate sampling, should be revised for conventional mills and heap leach facilities and updated to include an alternative sampling strategy for ISR facilities that primarily release radon gas.

OPERATIONAL MONITORING AIR SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.2.A	All	Air sampling locations should be consistent with the siting criteria in Section 3.1.1.1
3.1.3.2.B	All	Radon monitoring locations should be consistent with the preoperational monitoring program (see Recommendation I in Section 3.1.1.1).

OPERATIONAL MONITORING AIR SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.2.C	All	The frequency of replacing air particulate filters should be consistent with the approach defined during the preoperational monitoring phase and radon detectors should continue to be deployed for at least three months.

OPERATIONAL MONITORING WATER SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.3.A	All	Sampling frequencies described in the current guidance for monitoring wells located hydrologically upgradient and downgradient and flowing surface water should be revised to "at least quarterly."
3.1.3.3.B	All	The sampling location guidance should be changed to recommend that the sampling locations default to those established for preoperational sampling. Reduced or additional proposed operational locations should be included in the license request.
3.1.3.3.C	All	The current guidance stating that unusual releases should be sampled should be retained.

Operational Monitoring Vegetation, Food, and Fish Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.4.A	All	The locations and frequency described in the current guidance to obtain forage vegetation samples should be retained.
3.1.3.4.B	All	The language and recommendation in Footnote (o) from Table 2 of the current guide should be revised entirely to be consistent with the recommendations in RG 4.1 Rev. 2 associated with sample media. The revised language should be incorporated within the body of the main text under vegetation sampling in the revision of RG 4.14.
3.1.3.4.C	All	The locations and frequency described in the current guidance to obtain crop samples (including those from vegetable gardens) or livestock samples should be updated to include the option to obtain samples of game animals.
3.1.3.4.D	All	The locations and frequency described in the current guidance to obtain fish samples should be retained.

Operational Monitoring Soil Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.5.A	All	Licensees should continue to collect soil samples annually, using a consistent technique, at each of the locations chosen for air particulate samples, as specified in the current guidance.
3.1.3.5.B	ISR	Given the nature of uranium recovery operations at ISR facilities, additional or alternative soil sample locations should be collected in the areas where recovery operations are conducted.

Operational Monitoring Soil Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.5.C	ISR	Licensees should conduct gamma radiation scans at the preoperational grid transects at least every 5 years during the operational phase.

Operational Monitoring Sediment Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.6.A	All	Licensees should continue to collect sediment samples annually from the surface water locations, as specified in the current guidance.

Operational Monitoring Direct Radiation		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.7.A	All	The direct radiation measurements should be performed on a quarterly basis at air monitoring station locations.
3.1.3.7.B	ISR	Licensees should conduct scans at the original grid measurement locations (or a percentage of those locations), as well as in public access areas, at least every 5 years.

OPERATIONAL MONITORING RADON FLUX MEASUREMENTS		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.3.8.A	All	Radon flux measurements should continue to be excluded from the future revision of RG 4.14.

FREQUENCY AND ANALYSIS OF OPERATIONAL SAMPLES STACK SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.4.1.A	All	The updated guidance should encourage licensees to determine the method(s) to analyze stack samples and submit the information to NRC.

FREQUENCY AND ANALYSIS OF OPERATIONAL SAMPLES AIR SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.4.2.A	All	The radiological contaminants should match those specified in the frequency and analysis of preoperational air samples in Section 3.1.2.1.
3.1.4.2.B	All	The updated guidance should include information on the method(s) to analyze the content of airborne radiological contaminants.
3.1.4.2.C	All	The updated guidance should encourage licensee to include information on the method(s) to analyze devices used for radon monitoring.

FREQUENCY AND ANALYSIS OF OPERATIONAL SAMPLES WATER SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.4.3.A	All	The current guidance should be updated to remove Po-210 and reflect that the operational sampling scheme is equivalent to (defaults to) the preoperational sampling scheme.

FREQUENCY AND ANALYSIS OF OPERATIONAL SAMPLES Vegetation, Food, and Fish Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.4.4.A	All	The analysis for Ra-226 and Pb-210 in vegetation, food, and fish (edible portion) should continue per the current guidance.

FREQUENCY AND ANALYSIS OF OPERATIONAL SAMPLES SOIL AND SEDIMENT SAMPLES		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.4.5.A	All	The analysis in the current guidance should continue for radionuclides specified in soil (U-nat, Ra-226, and Pb-210) and sediment (U-nat, Th-230, Ra-226, and Pb-210). Because no changes are recommended, these two media are discussed concurrently.

Quality of Samples		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.5.A	All	Applicants or licensees should obtain representative samples for each of the media listed in this guidance in accordance with current regulatory requirements, acceptable industry practices, and approved site-specific plans and procedures.
3.1.5.B	All	Airborne particulate samples may be composited (e.g., batched) for analysis based on sample representativeness, sampling location, and monitoring period.
3.1.5.C	All	Samples of soil, vegetation/foliage, food, and water samples may be composited by location to estimate the mean concentration of the contaminant of interest and to collect sufficient sample mass or volume to meet the DQOs and measurement quality objectives (MQOs).
3.1.5.D	All	Radon detectors should be analyzed upon completion of their monitoring period.

Solubility of Airborne Radioactive Material		
	Applicability[1]	**Recommendation**
3.1.6.A	All	Section 4 should be revised to reflect current NRC regulatory requirements based on international and national guidance recommendations.

Lower Limit of Detection		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.7.A	All	The term lower limit of detection (LLD) should be renamed the minimum detectable concentration (MDC).

Lower Limit of Detection		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.7.B	All	Applicants or licensees should use 10% of the appropriate radionuclide concentration values listed in Table 2 of Appendix B to 10 CFR 20 as the MDC for stack effluent and environmental air and water samples.
3.1.7.C	All	Licensees should be provided alternative methods to calculate MDCs.
3.1.7.D	All	Po-210 and its associated MDC should be removed from consideration in the revised regulatory guidance.

Precision and Accuracy of Results		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.8.A	All	The combined standard uncertainty of a measurement should be estimated and reported along with its corresponding measurement value.
3.1.8.B	All	All sampling and measuring equipment should be adequately calibrated prior to use and their operation periodically verified.
3.1.8.C	All	The overall quality of the results should be preserved by licensee site-specific QA programs, procedures, and protocols.

Recording and Reporting of Results		
Chapter 3 Section	**Applicability[1]**	**Recommendation**
3.1.9.A	All	Applicants or licensees should report analytical results with sufficient sample information to readily identify the sample, sampling location, environmental conditions at the time of collection, associated uncertainties, and their relationship to regulatory limits.
3.1.9.B	All	Records should be properly maintained and readily available.
3.1.9.C	All	Measurement uncertainties should be estimated, recorded, and reported in accordance with established DQOs and MQOs.
3.1.9.D	All	All results should be presented in units that are appropriate for the measured/analyzed parameter.
3.1.9.E	All	All results should be reported to the number of significant figures warranted by the uncertainty approximation or as required by the NRC.
3.1.9.F	All	The report formatting should follow the generic example provided in Appendix D of this document for radiological data.

Other Recommendations		
Chapter 4 Section	**Applicability[1]**	**Recommendation**
All sections	All	The current RG 4.14 does not include guidance for conducting a land use census in the uranium recovery facility surroundings. Therefore, the revision to RG 4.14 should be expanded to include information on how to conduct a land use census (Chapter 4).
Appendix E (cited in this chapter)	All	Given the flexibility on multiple areas of this TBD, additional information regarding integrated risk-informed decision making (Appendix E) was incorporated to guide the performance of the recommendations included in this TBD.

APPENDIX B

PREOPERATIONAL MONITORING PROGRAM

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TABLE B-1
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
AIR						
Particulates	At least three[a]	Locations at or near the site boundary as required to monitor at least 50% of the annual wind rose frequency distribution and in different sectors that have the highest predicted concentrations of airborne particulates.	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least one	At or close to the nearest residence(s) or occupiable offsite structure(s) and at the nearest residence(s) or offsite occupiable structure(s) in the predominant wind direction within 10 km of site boundary. If the nearest residence or offsite occupiable structure is not located within the predominant wind direction, an air sampling station should be placed at that location.	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least one [b]	At a control or background location remote from site[b] preferably in the least prevalent wind direction	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
Radon Gas[c]	To be determined on a site-specific basis	Same locations as for air particulates and additional locations as evaluated by the applicant	Passive integrating (e.g., track etch)	At least quarterly	At least quarterly	As appropriate to quantify Rn-222

TABLE B-1
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	**Location**	**Method**	**Frequency**	**Frequency**	**Type of Analysis**
WATER						
Ground Water	At least six	Wells within 2 km of proposed disposal areas: at least three wells hydrologically downgradient and at least three wells located on other sides	To be determined based on aquifer conditions(d)	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226(e), Th-230, and Pb-210
	At least one from each well	Private wells within 2 km of proposed disposal areas that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions(d)	At least quarterly	At least quarterly	As appropriate to quantify dissolved and suspended natural uranium, Ra-226(e), Th-230, and Pb-210
	At least one	Wells within 2 km of the proposed disposal areas located hydrologically upgradient from proposed disposal areas	To be determined based on aquifer conditions(d)	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226(e), Th-230, and Pb-210
Surface Water	At least one from each impoundment	Onsite natural and man-made water impoundments within 2 km of the proposed disposal areas	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226(e), Th-230, and Pb-210
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least monthly	At least monthly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226(e), Th-230, and Pb-210

TABLE B-1
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
VEGETATION, FOOD, AND FISH						
Vegetation	At least three per sampling event (at least nine total per grazing period)	From animal grazing areas (including wetland plants) near the site in different sectors that will have the highest predicted air particulate concentrations due to facility operations	Grab	Three times during grazing season	Three times	As appropriate to quantify natural uranium, Pb-210, Ra-226, and Th-230
Food	At least three of each type	Crops, livestock, etc., raised within 3 km of site boundary	Grab	Time of harvest or slaughter	Once	As appropriate to quantify natural uranium, Pb-210, Ra-226, and Th-230
Fish	Each body of water	Fish from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by disposal impoundments failure	Grab	Semiannually	Twice	As appropriate to quantify natural uranium, Pb-210, Ra-226, and Th-230
SOIL AND SEDIMENT						
Surface Soil[f]	Up to thirty-five	To be determined on a site-specific basis using a Cartesian grid	Sample to a depth of 15 cm using an appropriate field sampling method	Once prior to site construction; repeat for locations disturbed by excavation, leveling, or contouring	Once	As appropriate to quantify all samples for Ra-226; 10% of samples for natural uranium, Th-230, and Pb-210
	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Sample to a depth of 5 cm using an appropriate field sampling method	Once prior to site construction	Once	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210

TABLE B-1
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Subsurface Soil Profile[g]	Up to five	To be determined on a site-specific basis using a Cartesian grid	Sample to a depth of 1 m using an appropriate field sampling method	Once prior to site construction; repeat for locations disturbed by excavation, leveling, or contouring	Once	As appropriate to quantify all samples for Ra-226; and at least one sample for natural uranium, Th-230, and Pb-210
Sediment[h]	At least one from each water impoundment	Onsite natural and man-made water impoundments within 2 km of the proposed disposal areas	Grab	Once prior to site construction	Twice	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	Grab	Once following spring runoff and late summer following period of extended low flow	Twice	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
DIRECT RADIATION						
	Up to eighty	To be determined on a site-specific basis using a Cartesian grid	Various (e.g., passive integrating device, pressurized ionization chamber, or properly calibrated portable survey instrument)	Once prior to site construction; repeat for areas disturbed by site preparation or construction	Once	Gamma exposure, exposure rate, etc.

TABLE B-1 PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES						
Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	N/A	If direct radiation measurements are not taken at the (up to) 80 locations, gamma scanning should be conducted within the proposed site boundary at the gamma scan transects determined on a site-specific basis using a Cartesian grid.	Gamma scanning	Once prior to site construction; repeat for areas disturbed by site preparation or construction	Once	Gross counts, count rate, exposure rate, etc.
	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Various (e.g., passive integrating device, pressurized ionization chamber, or properly calibrated portable survey instrument)	Once prior to site construction	Once	Gamma exposure, exposure rate, etc.

Footnotes for Table B-1:

(a) If the applicant determines that less than three samples, e.g., two samples, meet or exceed 50% of the onsite annual wind rose frequency distribution then the number may be reduced with proper justification and approval from the NRC.
(b) Care should be taken in selection of the control sampling location so that it is representative of the site conditions. In general, a location in the least prevalent wind direction from the site should provide a suitable location for a control sampling site. If applicants have more than one control air sampling location, the applicants should use the average of the control sample results.
(c) The use of alpha track-etch detectors is an acceptable method for measuring environmental levels of radon in air.
(d) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(e) If site initial sampling indicates the presence of Th-232, then Ra-228 should be considered in the background sampling or an alternative may be proposed, as indicated in NUREG-1569.
(f) Surface soil samples should be collected using a consistent technique to specified depth.
(g) Subsurface soil profile samples should be collected to a depth of one meter. Samples should be divided into three equal sections for analysis.
(h) Several samples should be collected at each location and composited as a representative sample.

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
AIR						
Particulates	At least three[a]	Locations at or near the boundary of the CPP, satellite facility, and any other facility that handles, stores or processes large quantities of source materials, as required to monitor at least 50% of the annual wind rose frequency distribution and in different sectors that have the highest predicted concentrations of airborne particulates	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least one	At or close to the nearest residence(s) or occupiable offsite structure(s) and at the nearest residence(s) or occupiable structure(s) in the predominant wind direction within 10 km of boundary of the CPP, satellite facility and any other facility that handles, stores or processes large quantities of source materials If the nearest residence or offsite occupiable structure is not located within the predominant wind direction, an air sampling station should be placed at that location.	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least one[b]	At a control or background location remote from site[b] with the least prevalent wind direction or at the nearest town or population density center unaffected by site operations	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210

Table: TABLE B-2 PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Radon Gas[c]	To be determined on a site-specific basis	Same locations as for air particulates and additional locations as evaluated by the applicant	Passive integrating (e.g., track etch)	At least quarterly	At least quarterly	As appropriate to quantify Rn-222
WATER						
Ground Water	At least one from each aquifer	• At least one upgradient and one downgradient monitoring well in the uppermost, overlying, underlying, and production zone aquifers within the 2 km buffer of each proposed ISR wellfield • At least one monitoring well in each of the following aquifers in each proposed ISR wellfield: uppermost, overlying, underlying, and production zone • If any evaporation or storage impoundments will be used, applicants should screen at least one upgradient well and two downgradient wells within the uppermost aquifer around the impoundment to detect any ground water degradation due to impoundment leakage	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
	At least one from each	Private wells within 2 km of proposed ISR wellfield and proposed disposal area that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved and suspended natural uranium, Ra-226[e], Th-230, and Pb-210

TABLE B-2
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least three	At least one well located hydrologically upgradient to proposed evaporation or storage water impoundments; and at least two wells located hydrologically downgradient within the uppermost aquifer	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
Surface Water	At least one from each body of water	Onsite natural and man-made water impoundments within 2 km of each proposed ISR wellfield	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined documented in facility procedures and protocols	At least monthly	At least monthly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
VEGETATION, FOOD, AND FISH						
Vegetation	At least three per sampling event (at least nine total per grazing period)	From animal grazing areas (including wetland plants) near the site in different sectors that will have the highest predicted air particulate concentrations during milling operations	Grab	Three times during grazing season	Three times	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210

TABLE B-2
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Food	At least three of each type	Crops, livestock, etc., raised within 3 km of the proposed boundary of the CPP, satellite facilities and any other facility that handles, stores or processes last quantities of source materials	Grab	Time of harvest or slaughter	Once	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
Fish	Each body of water	Fish from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by disposal impoundments failure	Grab	Semiannually	Twice	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
SOIL AND SEDIMENT						
Surface Soil[f]	Up to thirty-five	To be determined on a site-specific basis using a Cartesian grid	Sample to a depth of 15 cm using an appropriate field sampling method	Once prior to site construction; repeat for location disturbed by excavation, leveling or contouring	Once	As appropriate to quantify all samples for Ra-226, 10% of samples for natural uranium, Pb-210, and Th-230
	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Sample to a depth of 5 cm using an appropriate field sampling method	Once prior to site construction	Once	As appropriate to quantify natural uranium, Ra-226, Pb-210, and Th-230
Subsurface Soil Profile[g]	Up to five	To be determined on a site-specific basis using a Cartesian grid	Sample to a depth of 1 m using an appropriate field sampling method	Once prior to site construction; repeat for locations disturbed by excavation, leveling or contouring	Once	As appropriate to quantify all samples for Ra-226; and at least one sample for natural uranium, Pb-210, and Th-230

TABLE B-2
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Sediment[h]	At least one from each water impoundment	Onsite natural and man-made water impoundments within 2 km of each proposed ISR wellfield	Grab	Once prior to site construction	Once	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	Grab	Once following spring runoff and late summer following period of extended low flow	Twice	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
DIRECT RADIATION						
	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Various (e.g., passive integrating, pressurized ionization chamber, or properly calibrated portable survey instrument)	Once prior to site construction	Once	Gamma exposure, exposure rate, etc.

TABLE B-2
PREOPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	N/A	Gamma scanning should be conducted within the proposed boundary of the CPP, satellite facility, and any other facility that handles, stores or processes large quantities of source materials at the gamma scan transects determined on a site-specific basis using a Cartesian grid. Judgmental (biased) samples should be taken at anomalous locations	Gamma scanning (and judgmental sampling as needed using appropriate sampling protocols)	Once prior to site construction; repeat for areas disturbed by site preparation or construction	Once	Gross counts, count rate, exposure rate, etc. Refer to soil section of this table for judgmental sampling analysis

Footnotes for Table B-2:

(a) If the applicant determines that less than three samples, e.g., two samples, meet or exceed the onsite annual wind rose frequency distribution then the number may be reduced with proper justification and approval from the NRC.
(b) Care should be taken in selection of the control sampling location so that it is representative of the site conditions. In general, a location in the least prevalent wind direction from the site should provide a suitable location for a control sampling site. Also, a town or population density center that is not in the least prevalent wind direction is acceptable, but it should be necessary for the applicant to demonstrate that the control location is beyond the influence of the site. If applicants have more than one control air sampling location, the applicants should use the average of the control sample results.
(c) The use of alpha track-etch detectors is an acceptable method for measuring environmental levels of radon in air.
(d) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(e) If site initial sampling indicates the presence of Th-232, then Ra-228 should be considered in the background sampling or an alternative may be proposed, as indicated in NUREG-1569.
(f) Surface soil samples should be collected using a consistent technique to the specified depth(s).
(g) Subsurface soil profile samples should be collected to a depth of one meter. Samples should be divided into three equal sections for analysis.
(h) Several samples should be collected at each location and composited as a representative sample.

TABLE B-3

PREOPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
WATER						
Ground Water	At least six	Wells within 2 km of proposed disposal areas: at least three wells hydrologically downgradient and at least three wells located on other sides	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least one from each well	Private wells within 2 km of proposed disposal areas that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least one	Wells within 2 km of the proposed disposal areas located hydrologically upgradient from proposed disposal areas	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]

TABLE B-3
PREOPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Surface Water	At least one from each impoundment	Onsite natural and man-made water impoundments within 2 km of the proposed disposal areas	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least monthly	At least monthly	To be determined based on operational processes; to include general water quality parameters[c] and hazardous constituents

Footnotes for Table B-3:

(a) The non-radiological monitoring program is only applicable to ground water and surface water.
(b) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(c) As established in 10 CFR 40 Appendix A, Criterion 13 and NUREG-1569.

TABLE B-4
PREOPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR IN SITU RECOVERY FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
WATER						
Ground Water	At least one from each aquifer	• At least one upgradient and one downgradient monitoring well in the uppermost, overlying, underlying, and production zone aquifers within the 2 km buffer of each proposed ISR wellfield • At least one monitoring well in each of the following aquifers in each proposed ISR wellfield: uppermost, overlying, underlying, and production zone • If any evaporation or storage impoundments will be used, applicants should screen at least one upgradient well and two downgradient wells within the uppermost aquifer around the impoundment to detect any ground water degradation due to impoundment leakage	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least one from each	Private wells within 2 km of proposed ISR wellfield and proposed disposal areas that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least three	At least one well located hydrologically upgradient to proposed evaporation or storage water impoundments; and at least	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water

TABLE B-4
PREOPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR IN SITU RECOVERY FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
		two wells located hydrologically downgradient within the uppermost aquifer				quality parameters and hazardous constituents[c]
Surface Water	At least one from each	Onsite natural and man-made water impoundments within 2 km of the proposed disposal areas	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least monthly	At least monthly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]

Footnotes for Table B-4:

(a) The non-radiological monitoring program is only applicable to ground water and surface water.
(b) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(c) As established in 10 CFR 40 Appendix A, Criterion 13 and NUREG-1569.

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APPENDIX C

OPERATIONAL MONITORING PROGRAM

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TABLE C-1
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
STACKS						
Particulates	One for each	Yellowcake dryer and packaging stack(s)	Representative (e.g., ANSI N13.1)	To be determined on a site-specific basis	Each sample	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	One for each	Other stacks	Representative or grab (grab sampling based on consideration of location and frequency)	To be determined on a site-specific basis	Each sample	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
AIR						
Particulates	At least three[a]	Locations at or near the site boundary as required to monitor at least 50% of the annual wind rose frequency distribution and in different sectors that have the highest predicted concentrations of airborne particulates.	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least one	At or close to the nearest residence(s) or occupiable offsite structure(s) and at the nearest residence(s) or offsite occupiable structure(s) in the predominant wind direction within 10 km of site. If the nearest residence or offsite occupiable structure is not located within the predominant wind direction, an air sampling station should be placed at that location.	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210

TABLE C-1
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least one[b]	At a control or background location remote from site[b] preferably in the least prevalent wind direction	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
Radon Gas[c]	To be determined on a site-specific basis	Same locations as for air particulates and additional locations as evaluated by the applicant	Passive integrating (e.g., track etch)	At least quarterly	At least quarterly	As appropriate to quantify Rn-222
WATER						
Ground Water	At least six	Wells within 2 km of proposed disposal areas: at least three wells hydrologically downgradient and at least three wells located on other sides	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
	At least one from each well	Private wells within 2 km of proposed disposal areas that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved and suspended natural uranium, Ra-226[e],Th-230, and Pb-210
	At least one	Wells within 2 km of the proposed disposal areas located hydrologically upgradient from proposed disposal areas	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
Surface Water	At least one from each impoundment	Onsite natural and man-made water impoundments within 2 km of the proposed disposal areas	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226[e], Th-230, and Pb-210

TABLE C-1
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
VEGETATION, FOOD, AND FISH[f]						
Vegetation	At least three per sampling event (at least nine total per grazing period)	From animal grazing areas (including wetland plants) near the site in different sectors that will have the highest predicted air particulate concentrations due to facility operations	Grab	Three times during grazing season	Three times	As appropriate to quantify Pb-210 and Ra-226
Food	At least three of each type	Crops, livestock, etc., raised within 3 km of site boundary	Grab	Time of harvest or slaughter	Once	As appropriate to quantify Pb-210 and Ra-226
Fish	Each body of water	Fish from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by disposal impoundments failure	Grab	Semiannually	Twice	As appropriate to quantify Pb-210 and Ra-226
SOIL AND SEDIMENT						
Surface Soil[g]	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Sample to a depth of 5 cm using an appropriate field sampling method	Annually	Annually	As appropriate to quantify natural uranium, Pb-210, and Ra-226

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Sediment[h]	At least one from each water impoundment	Onsite natural and man-made water impoundments within 2 km of each proposed disposal area	Grab	Annually	Annually	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	Grab	Annually	Annually	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
DIRECT RADIATION						
	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Various (e.g., passive integrating device, pressurized ionization chamber, or properly calibrated portable survey instrument)	Quarterly	Quarterly	Gamma exposure, exposure rate, etc.

Table caption: **TABLE C-1 — OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES**

Footnotes for Table C-1:

(a) If the licensee determines that less than three samples, e.g., two samples, meet or exceed the onsite annual wind rose frequency distribution then the number may be reduced with proper justification and approval from the NRC.

(b) Care should be taken in selection of the control sampling location so that it is representative of the site conditions. In general, a location in the least prevalent wind direction from the site should provide a suitable location for a control sampling site. If licensees have more than one control air sampling location, the licensees should use the average of the control sample results.

(c) The use of alpha track-etch detectors is an acceptable method for measuring environmental levels of radon in air
(d) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(e) If site initial sampling indicates the presence of Th-232, then Ra-228 should be considered in the background sampling or an alternative may be proposed, as indicated in NUREG-1569.
(f) Sampling of vegetation may be needed if the land use census shows that a significant amount of vegetables/crops are grown locally, and an evaluation shows that vegetable consumption contributes a 20% dose increment to the total individual dose.
(g) Surface soil samples should be collected using a consistent technique to specified depth(s).
(h) Several samples should be collected at each location and composited as a representative sample.

TABLE C-2
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
STACKS						
Particulates	One for each	Yellowcake dryer and packaging stack(s)	Representative (e.g., ANSI N13.1)	To be determined on a site-specific basis	Each sample	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	One for each	Other stacks	Representative or grab (grab sampling based on consideration of location and frequency)	To be determined on a site-specific basis	Each sample	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
AIR						
Particulates	At least three[(a)]	Locations at or near the boundary of the CPP, satellite facility, and any other facility that handles, stores or processes large quantities of source materials, as required to monitor at least 50% of the annual wind rose frequency distribution and in different sectors that have the highest predicted concentrations of airborne particulates	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210

TABLE C-2
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least one	At or close to the nearest residence(s) or occupiable offsite structure(s) and at the nearest residence(s) or occupiable structure(s) in the predominant wind direction within 10 km of boundary of the CPP, satellite facility and any other facility that handles, stores or processes large quantities of source materials. If the nearest residence or offsite occupiable structure is not located within the predominant wind direction, an air sampling station should be placed at that location.	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
	At least one[b]	At a control or background location remote from site[b] with the least prevalent wind direction or at the nearest town or population density center unaffected by site operations	Continuous	To be determined on a site-specific basis	To be determined on a site-specific basis	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
Radon Gas[c]	To be determined on a site-specific basis	Same locations as for air particulates and additional locations as evaluated by the licensee	Passive integrating (e.g., track etch)	At least quarterly	At least quarterly	Rn-222

TABLE C-2
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
WATER						
Ground Water	At least one from each aquifer	• At least one upgradient and one downgradient monitoring well in the uppermost, overlying, underlying, and production zone aquifers within the 2 km buffer of each ISR wellfield • At least one monitoring well in each of the following aquifers in each ISR wellfield: uppermost, overlying, underlying, and production zone • If any evaporation or storage impoundments are used, licensees should screen at least one upgradient well and two downgradient wells within the uppermost aquifer around the impoundment to detect any ground water degradation due to impoundment leakage	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
	At least one from each	Private wells within 2 km of ISR wellfield and disposal areas that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved and suspended natural uranium, Ra-226[e], Th-230, and Pb-210
	At least three	At least one well located hydrologically upgradient to evaporation or storage water impoundments; and at least two wells located hydrologically downgradient within the uppermost aquifer	To be determined based on aquifer conditions[d]	At least quarterly	At least quarterly	As appropriate to quantify dissolved natural uranium, Ra-226[e], Th-230, and Pb-210

TABLE C-2
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Surface Water	At least one from each body of water	Onsite natural and man-made water impoundments within 2 km of each ISR wellfield	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	As appropriate to quantify suspended and dissolved natural uranium, Ra-226[e], Th-230, and Pb-210
VEGETATION, FOOD, AND FISH[f]						
Vegetation	At least three per sampling event (at least nine total per grazing period)	From animal grazing areas (including wetland plants) near the site in different sectors that will have the highest predicted air particulate concentrations during milling operations	Grab	Three times during grazing season	Three times	As appropriate to quantify Ra-226 and Pb-210
Food	At least three of each type	Crops, livestock, etc., raised within 3 km of the of the boundary of the CPP, satellite facility, and any other facility that handles, stores or processes large quantities of source materials	Grab	Time of harvest or slaughter	Once	As appropriate to quantify Ra-226 and Pb-210

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
Fish	Each body of water	Fish from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas or that could be affected by disposal impoundments failure	Grab	Semiannually	Twice	As appropriate to quantify Ra-226 and Pb-210
SOIL AND SEDIMENT						
Surface Soil[g]	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Sample to a depth of 5 cm using an appropriate field sampling method	Annually	Annually	As appropriate to quantify natural uranium, Pb-210, and Ra-226
	To be determined on a site-specific basis	Locations where recovery operations are conducted (e.g., at wellfields)	Use appropriate depth and field sampling method	Annually	Annually	As appropriate to quantify natural uranium, Pb-210, and Ra-226
	N/A	Gamma scanning should be conducted within the boundary of CPP, satellite facility, and any other facility that handles, stores or processes large quantities of source materials, at the gamma scan transects determined on a site-specific basis using a Cartesian grid. Judgmental (biased) samples should be taken at anomalous locations.	Gamma scanning (and judgmental sampling as needed using appropriate sampling protocols)	Every five years	Every five years	Gross counts, count rate, exposure rate, etc. Refer to soil section of this table for judgmental sampling analysis
Sediment[h]	At least one from each water impoundment	Onsite natural and man-made water impoundments within 2 km of each ISR wellfield	Grab	Annually	Annually	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210

TABLE C-2
OPERATIONAL RADIOLOGICAL MONITORING PROGRAM FOR IN SITU RECOVERY FACILITIES

Type of Media or Measurement	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	Grab	Annually	Annually	As appropriate to quantify natural uranium, Ra-226, Th-230, and Pb-210
DIRECT RADIATION						
	To be determined on a site-specific basis	At same locations used for collection of air particulate samples	Various (e.g., passive integrating, pressurized ionization chamber, or properly calibrated portable survey instrument)	Quarterly	Quarterly	Gamma exposure, exposure rate, etc.
	N/A	Gamma scanning should be conducted within the boundary of the CPP, satellite facility, and any other facility that handles, stores or processes large quantities of source materials, at the gamma scan transects determined on a site-specific basis using a Cartesian grid. Judgmental (biased) samples should be taken at anomalous locations.	Gamma scanning (and judgmental sampling as needed using appropriate sampling protocols)	Every five years	To be determined on a site-specific basis	Gross counts, count rate, exposure rate, etc. Refer to soil section of this table for judgmental sampling analysis

Footnotes for Table C-2 on next page

Footnotes for Table C-2:

(a) If the licensee determines that less than three samples, e.g., two samples, meet or exceed the onsite annual wind rose frequency distribution then the number may be reduced with proper justification and approval from the NRC.
(b) Care should be taken in selection of the control sampling location so that it is representative of the site conditions. In general, a location in the least prevalent wind direction from the site should provide a suitable location for a control sampling site. Also, a town or population density center that is not in the least prevalent wind direction is acceptable, but it should be necessary for the licensee to demonstrate that the control location is beyond the influence of the site. If licensees have more than one control air sampling location, the licensees should use the average of the control sample results.
(c) The use of alpha track-etch detectors is an acceptable method for measuring environmental levels of radon in air.
(d) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(e) If site initial sampling indicates the presence of Th-232, then Ra-228 should be considered in the background sampling or an alternative may be proposed, as indicated in NUREG-1569.
(f) Sampling of vegetation may be needed if the land use census shows that a significant amount of vegetables/crops are grown locally, and an evaluation shows that vegetable consumption contributes a 20% dose increment to the total individual dose.
(g) Surface soil samples should be collected using a consistent technique to the specified depth(s).
(h) Several samples should be collected at each location and composited as a representative sample.

TABLE C-3

OPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
WATER						
Ground Water	At least six	Wells within 2 km of disposal areas: at least three wells hydrologically downgradient and at least three wells located on other sides	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least one from each well	Private wells within 2 km of disposal areas that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least one	Wells within 2 km of the disposal areas located hydrologically upgradient from disposal areas	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]

	TABLE C-3 OPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR CONVENTIONAL MILLS AND HEAP LEACH FACILITIES					
Type of Media	**Sample Collection**				**Sample Analysis**	
	Number	**Location**	**Method**	**Frequency**	**Frequency**	**Type of Analysis**
Surface Water	At least one from each impoundment	Onsite natural and man-made water impoundments within 2 km of the disposal areas	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]

Footnotes for Table C-3:

(a) The non-radiological monitoring program is only applicable to ground water and surface water.
(b) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(c) As established in 10 CFR 40 Appendix A, Criterion 13 and NUREG-1569.

TABLE C-4
OPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR IN SITU RECOVERY FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
WATER						
Ground Water	At least one from each aquifer	• At least one upgradient and one downgradient monitoring well in the uppermost, overlying, underlying, and production zone aquifers within the 2 km buffer of each ISR wellfield • At least one monitoring well in each of the following aquifers in each ISR wellfield: uppermost, overlying, underlying, and production zone • If any evaporation or storage impoundments are used, licensees should screen at least one upgradient well and two downgradient wells within the uppermost aquifer around the impoundment to detect any ground water degradation due to impoundment leakage	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents [c]
	At least three	At least one well located hydrologically upgradient to evaporation or storage water impoundments; and at least two wells located hydrologically downgradient within the uppermost aquifer	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]

TABLE C-4
OPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[a] FOR IN SITU RECOVERY FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least one from each	Private wells within 2 km of ISR wellfield and disposal area that are or could be used for drinking water, watering of livestock, or crop irrigation	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
	At least three	At least one well located hydrologically upgradient to evaporation or storage water impoundments; and at least two wells located hydrologically downgradient within the uppermost aquifer	To be determined based on aquifer conditions[b]	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]
Surface Water	At least one from each	Onsite natural and man-made water impoundments within 2 km of each proposed ISR wellfield	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[c]

TABLE C-4
OPERATIONAL NON-RADIOLOGICAL MONITORING PROGRAM[(a)] FOR IN SITU RECOVERY FACILITIES

Type of Media	Sample Collection				Sample Analysis	
	Number	Location	Method	Frequency	Frequency	Type of Analysis
	At least two from each body of water	For each stream, river, or other surface water or drainage system within the site boundary, at least one sample located hydrologically upgradient and at least one sample located hydrologically downgradient. Any stream beds that are dry part of the year should be sampled when water is flowing.	To be determined and documented in facility procedures and protocols	At least quarterly	At least quarterly	To be determined based on operational processes; to include general water quality parameters and hazardous constituents[(c)]

Footnotes for Table C-4:

(a) The non-radiological monitoring program is only applicable to ground water and surface water.
(b) The method and sampling device are to be specified in the environmental sampling plan SOP. The method specified should include purging to ensure that stagnant water is not sampled. Samples may be collected using a bailer or pump.
(c) As established in 10 CFR 40 Appendix A, Criterion 13 and NUREG-1569.

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APPENDIX D

SAMPLE FORMAT FOR REPORTING RADIOLOGICAL MONITORING DATA

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APPENDIX D

SAMPLE FORMAT FOR REPORTING RADIOLOGICAL MONITORING DATA[a]

1. Stack Samples

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Stack flow rate (m^3/s)

Radionuclide	Concentration (μCi/mL)	Uncertainty[b] (μCi/mL)	MDC[c] (μCi/mL)	Release Rate (Ci/quarter)	Uncertainty[b] (Ci/quarter)	% Effluent Concentration Value[d]

2. Air Samples

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection

Radionuclide	Concentration (μCi/mL)	Uncertainty[b] (μCi/mL)	MDC[c] (μCi/mL)	% Effluent Concentration Value[d]

3. Liquid Samples

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Type of sample (for example: surface, ground, drinking, stock, or irrigation)

Radionuclide	Concentration (μCi/mL)	Uncertainty[b] (μCi/mL)	MDC[c] (μCi/mL)	% Effluent Concentration Value[d]

4. Vegetation, Food, and Fish Samples

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Type of sample and portion analyzed

Radionuclide	Concentration (μCi/kg wet)	Uncertainty[b] (μCi/kg)	MDC[c] (μCi/kg)

5. Soil and Sediment Samples

For each sample analyzed, report the following information:

a. Date sample was collected
b. Location of sample collection
c. Type of sample and portion analyzed

Radionuclide	Concentration (μCi/g)	Uncertainty[b] (μCi/g)	MDC[c] (μCi/g)

6. Direct Radiation Measurements

For each measurement, report the dates covered by the measurement and the following information:

Location	Hand-Held Instrumentation		Passive Monitoring	
	Average Gamma Exposure Rate (mR/hr-quarter)	Uncertainty[b] (mR/hr-quarter)	DDE (mrem/quarter)	Uncertainty[b] (mrem/quarter)

Footnotes for Appendix C:

(a) This table illustrates format only. It may not include a complete list of data to be reported and associated units.
(b) The combined standard uncertainty of a measurement should be estimated by propagating the standard uncertainty of the individual components of the measurement.
(c) All calculations of the minimum detectable concentration (MDC) and percentages of limit should be included as supplemental information.
(d) Effluent concentration value, 10 CFR 20, Appendix B.

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APPENDIX E

INTEGRATED RISK-INFORMED DECISION MAKING

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INTEGRATED RISK-INFORMED DECISION MAKING

This appendix extends the Chapter 4 discussion on land use in support of a risk-informed approach as it relates to environmental monitoring programs for all three principal types of uranium recovery facilities. Facility releases and monitoring considerations are provided, including principal and secondary radionuclides and pathways or routes of exposure that should remain with the program during the preoperational and operational phases. Recommendations (and accompanying justifications) are provided to update the current regulatory guide and support the NRC's initiatives over the past several years as it contemplates a risk-informed regulatory framework.

The land use and risk-informed approach are related. Examples include the arrival of a new resident near a uranium recovery facility. The resident plants a garden, thereby creating a potential dose pathway and associated risk. Operationally, a licensee may initiate changes to the facility such as adding a second yellowcake vacuum dryer or an additional satellite facility. These changes impact the risk to operational workers and potentially impact the environmental risk to members of the public.

The NRC has also been examining a performance-based regulatory framework and a combined risk-informed/performance-based framework. Both approaches are briefly discussed later in this appendix. NUREG/CR-6733 discusses a risk-informed, performance-based approach for ISR facilities (NRC 2001).

E.1. RISK-INFORMED CONCEPTS

The NRC published a white paper in 1998 describing several of the key terms and concepts associated with a risk-informed approach (NRC 1998). This approach is rooted first in a basic understanding of other related terms, including "risk," "risk assessments," and "risk insights." Risk is described in terms of a "risk triplet" where questions are posed regarding what can go wrong, the likelihood of occurrence, and accompanying consequences. Consequently, a probability of occurrence, rather than a deterministic approach, is employed. This is important because the NRC's present regulations are primarily based on a traditional—i.e., deterministic and prescriptive requirements—approach. However, a deterministic approach explicitly answers only two of the three components of the risk triplet. Answers to the risk triplet questions guide the formulation of NRC requirements and drive regulatory attention towards the issues impacting the health and safety of the public and the environment.

A risk assessment follows the risk triplet to evaluate the performance of a particular system. At uranium recovery facilities, the risk assessment may focus on a variety of different hazards, from radiological to chemical. A risk assessment addressing the operation of a yellowcake dryer, for example, would examine factors such as likely outcomes if the dryer failed, its interactions with other operational systems, and related areas of uncertainty. A risk assessment approach and risk examples at ISR facilities are described in NUREG/CR-6733. Chapter 3 of this NUREG discusses environmental surface and groundwater hazards from radiological and chemical perspectives, respectively. Surface radiological risks are associated with liquids (slurrys, lixiviants, eluants, and bleeds), solids (loaded resins and yellowcake), and gaseous substances (radon and progeny). Once identified, consequence analyses were conducted for applicable substances. In summary, risk assessments can be applied to all uranium recovery facilities.

In addition to radiological hazards, a risk-informed approach can also be applied to non-radiological hazards associated with byproduct material, including groundwater in and near the wellfield affected by ISR operations. Byproduct material includes the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. As stated in 42 USC 2114 Sec 84(a)(1), *Authorities of Commission Respecting Certain Byproduct Material*, the management of any byproduct material, as defined in section 11e(2), is carried out to protect the public health and safety and the environment from radiological and non-radiological hazards associated with processing, possession, and transfer of byproduct material.

Representative hazards identified in NUREG/CR-6733 for surface chemical risks are ammonia, sulfuric acid, liquid and gaseous oxygen, hydrogen peroxide, carbon dioxide, sodium carbonate, hydrogen sulfide, and other chemicals. These chemicals are used to adjust acidity and alkalinity (pH), as oxidants and precipitants, resin regeneration, and groundwater restoration. As noted in the NUREG, groundwater radiological and chemical contamination hazards are of particular importance from a health standpoint to humans, livestock, and wildlife. Because no lixiviant excursions or spills are acceptable, NUREG/CR-6733 examines the frequency of occurrence for these events, the probability of detection, and offers recommendations and possible mitigating actions.

Risk insights are effectively summarized in the NRC white paper (NRC 1998) as the results and findings that come from conducting risk assessments and which directly drive public health effects. Utilizing risk insights has been advantageous from a regulatory process perspective and as a complement to the "traditional" (deterministic) approaches.

E.1.1. Risk-informed Approach

The NRC white paper (NRC 1998) provides the following information regarding this topic:

> *A "risk-informed" approach to regulatory decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to health and safety. A "risk-informed" approach enhances the traditional approach by: (a) allowing explicit consideration of a broader set of potential challenges to safety, (b) providing a logical means for prioritizing these challenges based on risk significance, operating experience, and/or engineering judgment, (c) facilitating consideration of a broader set of resources to defend against these challenges, (d) explicitly identifying and quantifying sources of uncertainty in the analysis, and (e) leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions. Where appropriate, a risk-informed regulatory approach can also be used to reduce unnecessary conservatism in deterministic approaches, or can be used to identify areas with insufficient conservatism and provide the bases for additional requirements or regulatory actions.*

In implementing a risk-informed approach, the NRC considers a set of five key principles (NRC 2012a), as illustrated in Figure E-1.

Until recently, a risk-informed approach has emphasized the field of reactor safety to address accident considerations. Figure E-1 cites five reactor-based general principles. Nonetheless, these principles can be applied, to varying degrees, to uranium recovery facilities. Note that these five concepts are not directly connected to each other (each arrow associated with Principle 1–5, respectively, feeds independently into the inner circle comprising the overall integrated decision-making approach.)

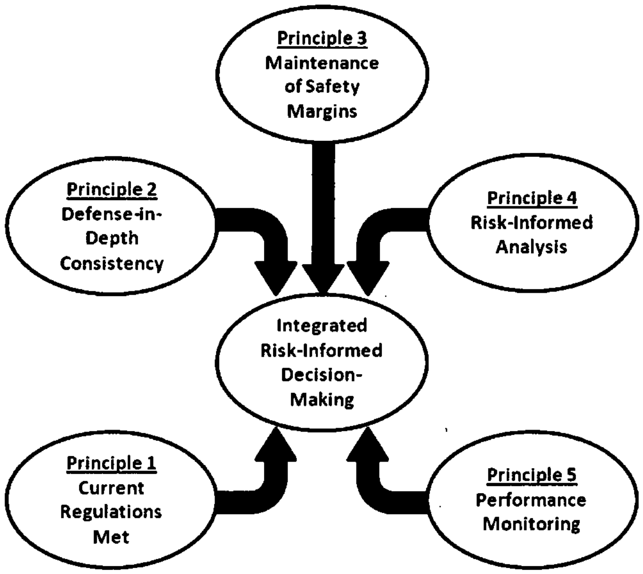


Figure E-1. Five Key Principles (source: NRC 2012a)

NRC RG 1.177, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Technical Specifications* (NRC 2011), discusses the five key risk-informed principles discussed in this chapter section. It considers risk insights and engineering decisions (e.g., defense-in-depth) specific to power reactors. Information provided in NRC RG 1.177 can be generally applied to uranium recovery facilities in areas such as uncertainties in equipment and human performance. ALARA considerations and dose models can be utilized at these facilities, using valid assumptions and site-specific data when available.

E.1.1.1. Principle #1: Current Regulations Met

The first key principle focuses on meeting the regulations germane to uranium recovery facilities. Meeting these requirements enhances the probability that the facility will operate safely and reduce risks to operating personnel and the public. These regulations include 10 CFR Part 40, Appendix A (primarily applicable to conventional uranium mills), 10 CFR Part 20, Sections 1301 and 1302 (addressing public dose limits and compliance with these limits, respectively), and 40 CFR Part 192. In addition, the NRC requires that licensees satisfy license conditions specific to their facility. Multiple guidance documents also support environmental and operational aspects of these facilities. Examples include NUREG/CR-6733, NUREG-1569, and NUREG-1910, the current RG 4.14 and other applicable category "4" environmental regulatory guides. Additional references are provided in this document.

E.1.1.2. Principle #2: Defense-in-Depth Consistency

The NRC has examined the issue of defense-in-depth for many years. The NRC defines defense-in-depth as "an approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials." The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon. Defense-in-depth includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures. (NRC 2012b). An example of defense-in-depth at uranium recovery facilities would be the use of multiple protective barriers (layers) at tailings, and evaporation ponds.

The intent of a defense-in-depth approach is to ensure that the environmental monitoring program views changes as those consistently affecting the environment and land use census. Implementing Principle #2 could be achieved through an ALARA Review Committee (or identified group) that ensures performance monitoring is consistent, risk-informed analyses are performed adequately (and consistently), and an adequate margin of safety is maintained.

E.1.1.3. Principle #3: Maintenance of Safety Margins

This principle requires a concerted, integrated approach and attention to safety, inclusive of all employees. Safety is a fundamental tenet at any facility; uranium recovery facilities are no exception. Management that embraces the NRC's safety culture or an integrated safety management philosophy enhances the margin of safety for all workers and, by extension, the public. Principle #3 could be applied through proper implementation of relevant regulations and standards (refer to Principle #1) and ALARA Review Committee meetings. The ALARA Committee could be authorized to maintain an adequate "margin of safety."

The primary margin of safety would include maintaining potential new changes (due to plant changes or land use census) below the 100 mrem/yr TEDE regulatory limit. As an example, if a uranium recovery facility were to double its operational annual output of yellowcake, the ALARA Review Committee should perform an environmental dose assessment (e.g., using RESRAD and MILDOS-AREA) on the existing monitoring locations to ensure that the TEDE is still within its margin of safety. The Committee would subsequently report its findings, including the numerical change or percentage increase in the projected maximum annual dose (and where that increase occurred) due to the increase in production. A satisfactory conclusion from the assessment would be to report that the revised annual TEDE was below (hopefully significantly below) the 100 mrem/yr limit and well within the margin of safety.

Another possible application of Principle #3 would be a periodic or annual review of all environmental data, including a comparison to the prior year (regardless of whether or not any changes to the plant or the land use census had occurred during that time). This approach would evaluate uranium recovery operations as a whole to ensure that radioactive materials were not migrating within the environment and reducing the margin of safety. This approach could be viewed as a trending analysis with a risk-informed analysis component.

E.1.1.4. Principle #4: Risk-informed Analysis

Elements of a risk-informed analysis are described earlier in this chapter. One application of this analysis should be to evaluate new land use information and plant modifications against existing locations. Dose assessment tools such as MILDOS-AREA or RESRAD could be used by the ALARA Review Committee to evaluate and compute a risk for each possible change (due to plant changes or land use census) and make recommendations to include or exclude the new location, as well as assess the impact of plant changes.

E.1.1.5. Principle #5: Performance Monitoring

Performance monitoring in the context of uranium recovery could be examined in several different ways. The current program could be reviewed to ensure that all programmatic elements were in place and functional. If a deficiency was identified, a program assessment would identify specific enhancements (e.g., the use of satellite infrared data to determine changes to the vegetation, incorporating a revised MILDOS-AREA program, a new and better software model).

Performance monitoring could also be evaluated in the form of a five year review of the changes made over that period to determine the potential impact on the environment. For example, a population growth trend could be identified due to the building and startup of a new manufacturing plant in the county where the uranium recovery facility was located. An associated increase in housing construction would be a conceivable outcome.

E.1.2. Performance-based Regulatory Approach

NRC has evaluated performance-based approaches for meeting regulatory standards. Performance-based approaches require the development of objective performance criteria predicated on deterministic safety analyses and performance history (NRC 1998).

A performance-based approach is not emphasized in this TBD, primarily because the development of objective criteria for performance monitoring at uranium recovery facilities is not currently available and may not be either partially or fully implementable. However, because this approach is based on achieving a desired measurable or calculable outcome while providing flexibility to the licensee to achieve that outcome, it could be potentially applied to various environmental monitoring activities. The NRC has stated that the adoption of a flexible framework may ultimately result in the application of a performance-based approach across "all materials, processes, and facilities" regulated by the NRC (NRC 1998).

E.1.3. Risk-informed, Performance-based Approach

A risk-informed, performance-based regulation combines characteristics of both risk-informed and performance-based approaches. It is an approach that relies on risk insights, engineering analysis and judgment (including the principle of defense-in-depth and the incorporation of safety margins), and performance history to (1) focus attention on the most important activities, (2) establish objective criteria for evaluating performance, (3) develop measurable or calculable parameters for monitoring system and licensee performance, (4) provide flexibility to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes, and (5) focus on the results as the primary basis for regulatory decision making.

E.2. INTEGRATED, RISK-INFORMED DECISION-MAKING APPROACH

The integrated, risk-informed decision-making approach is not new; it has been incorporated methodically for some time into various NRC regulatory guidance and regulations. Examples include NRC RG 4.1 (Revision 2) and NUREG/CR-6733. The risk-informed approach is described in RG 4.1, Section 4.a ("New Routes of Exposure") and Section 5.a ("Sample Media") and has applicability to uranium recovery facilities.

The risk-informed process has also been addressed internationally. The IAEA in Safety Standards Series: *Safety Assessment for Facilities and Activities*, General Safety Requirements Part 4 (IAEA 2009), for example, highlights the need for an integrated assessment for decision making. In particular, Section 5.8 of this Safety Standard states:

> *The results of the safety assessment have to be used to make decisions in an integrated, risk informed approach, by means of which the results and insights from the deterministic and probabilistic assessments and any other requirements are combined in making decisions on safety matters in relation to the facility or activity.*

A risk-informed approach, as emphasized in this TBD, requires consideration of several issues (both radiological and chemical) associated with environmental monitoring programs. These issues include sources of exposure information, translation of the radionuclides associated with the uranium recovery process into external and internal dose considerations, environmental pathway analysis (either deterministic, probabilistic, or both), and monitoring requirements (including methods, locations, and frequency). In addition, understanding the process at a specific facility may allow the licensee to increase or reduce the monitoring effort for radionuclide and chemical constituents.

At uranium recovery facilities, land use (refer to Chapter 4) has direct implications for a risk-informed approach and subsequent decision making. The results of the land use census should be a principal driver for modifications to environmental monitoring programs. If during an annual risk-informed analysis no significant changes in land use, or facility operations, are identified from the prior year, no modifications to the environmental program should be necessary. However, ultimately, risk-informed decisions should be based on the most current risk-informed data available. The obtained data and subsequent decisions should be compiled into a report and presented to the cognizant regulatory authority.

E.3. RADIOLOGICAL AND CHEMICAL ASSESSMENT

A radiological and chemical assessment should be performed during the operational phase at a uranium recovery facility. The outcomes of the assessment may be used to make decisions using an integrated, risk-informed approach.

Although this section mainly discusses the evaluation of radionuclides in different environmental media, the evaluation of chemicals is required by the NRC for groundwater and surface water. Regulatory requirements are cited in Section E.3.3. The chemical assessment is required to determine the chemical hazards that could potentially impact humans and the environment as a result of uranium recovery operations. The exposure and toxicity of chemical contaminants is not discussed since it is beyond the scope of this document, with the exception of the chemical toxicity of uranium which is presented as an example. Attachment E-I contains information on uranium intakes and its chemical toxicity. Other contaminants, whether radiological, chemical, or both, should be evaluated in a similar manner.

E.3.1. Facility Sources of Exposure

Sources of exposure from uranium recovery central processing plant and associated operations include but are not limited to stack emissions; fugitive dusts; tailings pile emissions; resuspension of contaminated soils; discharges to surface waters; horizontal and vertical excursions from wellfields; leaks from wellfield infrastructure including piping and well casings; land application infiltration; spills of process liquids and slurries; and leakage from settling ponds, evaporation ponds, and overflow basins. These releases can contain radiological and chemical contaminants. However, as noted previously, the chemical contaminants are of concern to the NRC for groundwater and surface water.

The radiological and chemical airborne and waterborne sources of exposure depend on the type of facility. Facility sources of exposure should be summarized for ease of reference and for consideration when performing estimates of doses or concentration of radionuclides or chemical contaminants released in the air (e.g., via stack) and liquid effluents. Table E-1 includes a summary of the potential radiological and chemical airborne and waterborne sources of exposure for all uranium recovery facilities.

Table E-1. Airborne and Waterborne Sources of Exposure at Uranium Recovery Facilities[a]

<table>
<tr><th rowspan="2">Facility</th><th colspan="2">Airborne</th><th>Waterborne</th></tr>
<tr><th>Particulate Sources</th><th>Radon Sources</th><th>Sources</th></tr>
<tr><td>Conventional Mills</td><td>– Ore handling
– Ore storage
– Ore crushing and grinding
– Conveying
– Ore feed system
– Yellowcake drying[b] and packaging
- Tailings piles</td><td>– Ore storage
– Ore crushing and grinding
– Ore feed system
– Mill tailings disposal site
– Evaporation ponds</td><td>– Ore stockpiles
– Leaching systems
– Counter current decantation thickening systems
– Uranium-solution extraction systems
– Ion exchange systems
– Tailings piles
– Evaporation ponds</td></tr>
<tr><td>Heap Leach</td><td>– Ore crushing
– Active heap piles
– Spent (leached) heap piles/areas
– Yellowcake drying[b] and packaging</td><td>– Active heap piles
– Process ponds
– Spent (leached) heap piles/areas
– Evaporation ponds</td><td>– Active heap piles
– Spent (leached) heap piles/areas
– Collection ponds
– Ion exchange systems
– Evaporation ponds</td></tr>
<tr><td>In Situ</td><td>– Yellowcake drying[b] and packaging</td><td>– Wellfields operations
– Operations of the central plant
– Resin transfer operations (when remote ion-exchange is used)
– Aquifer restoration activities
– Evaporation ponds</td><td>– Extraction process
– Wellfield operations
– Resin transfer operations
– Operation of central processing plants
– Aquifer restoration activities
– Evaporation/surge ponds/other impoundments
– Land application
– Surface water discharges</td></tr>
</table>

[a] The information in this table was obtained from NRC 1987 and 2009b; Faillace et al. 1997; Titan Uranium USA, Inc. 2011; Energy Fuels 2010; IAEA 1993 and 2002; and Strata Energy 2010.
[b] Source of exposure associated with facility designs utilizing a thermal dryer.

E.3.2. Pathway Analysis

An environmental pathway analysis, supported by an environmental transport conceptual site model (CSM), should be a required action for the licensee to undertake in order to understand how its facility and uranium recovery operation will impact the surrounding environs and the public. A CSM is a qualitative description of the environmental transport and exposure pathways and their interrelationships at a site (NRC 2006). It provides the framework for assessing current and possible future risks associated with exposures to radionuclides in the environment (Till and Grogan 2008). Additional details for developing a CSM are available in Till and Grogan 2008. The concepts and approach for developing a CSM discussed in Till and Grogan 2008 also apply to chemicals. Nevertheless, the CSM should provide an illustration of site conditions, which explains contaminant distributions, release mechanisms, exposure pathways and migration routes, and potential receptors (NRC 2006). The CSM is then supported by measurements (e.g., direct radiation), collection of media samples, analysis, and reporting.

Pathway analysis is the detailed study of the behavior and transport of releases from a facility to the environment, focusing on every credible route radioactive material could take until it is inhaled, ingested or absorbed (direct radiation) by a human; a useful pathway analysis summary is provided in NCRP Report No. 123, Vol. I (NCRP 1996). Air and water are the two primary environmental pathways. The simplest pathway is associated with airborne emissions that are carried downwind from the emission point and directly inhaled. Airborne emissions may be deposited on surface soils, resuspended by wind, and then inhaled. Atmospheric emissions may also deposit on surface waters, and from there enter the drinking water pathway and the aquatic food chain pathway, producing intakes via fish, shellfish, or aquatic plant consumption. Atmospheric releases deposited on ground may then move into the groundwater pathway, and again into drinking water supplies, or enter the terrestrial food chain pathway through deposition onto or absorption into food or forage crops, and in the case of the latter, into milk or meat for human consumption. The groundwater pathway may also reenter the terrestrial food chain pathway via irrigation. Typically, these analyses are performed with computer programs such as MILDOS-AREA (NRC 2003) and the RESRAD family of codes (Yu et al. 2001 and 2007).

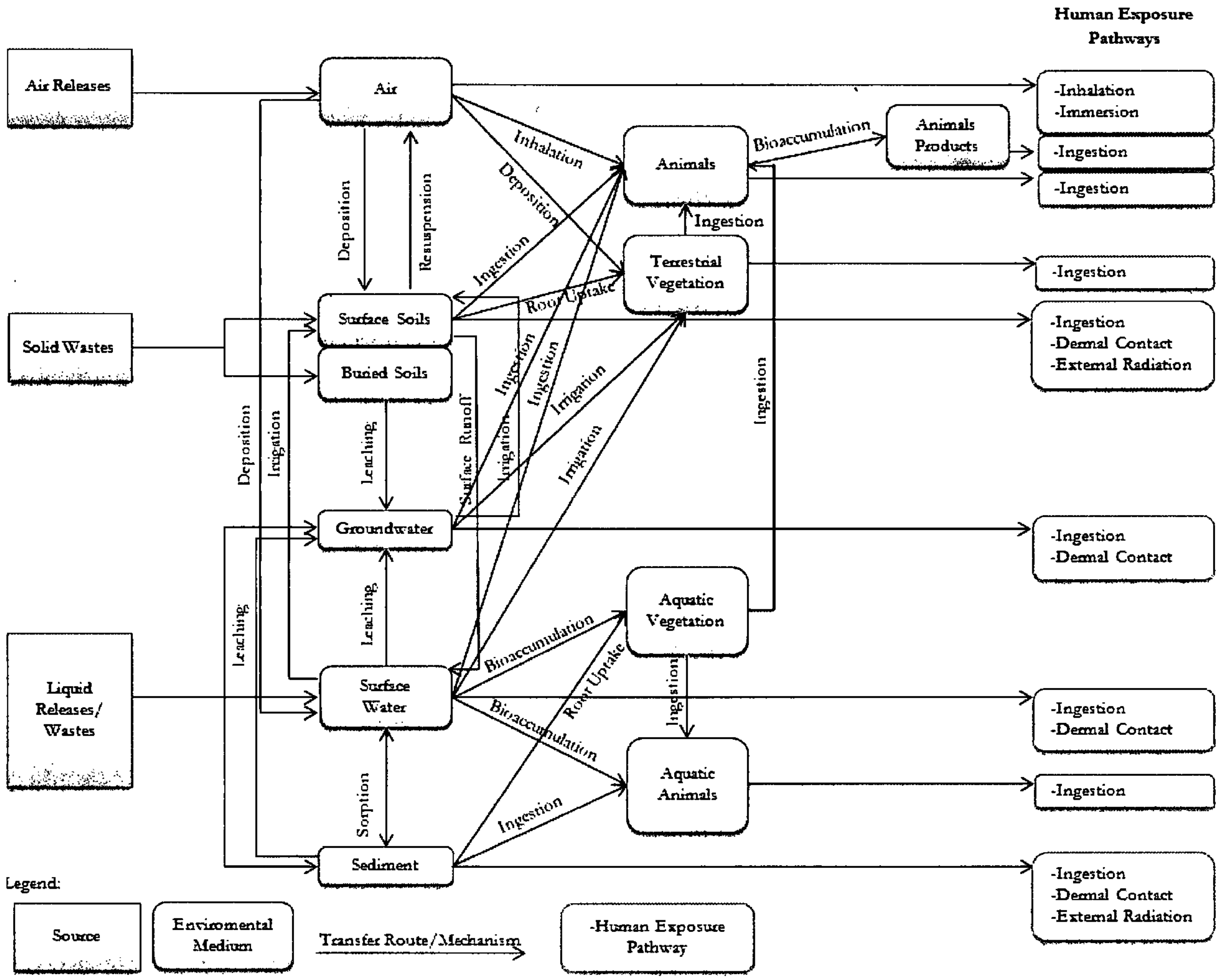
Internal doses to members of the public can be calculated by monitoring releases from facilities and using pathway analyses to calculate the concentrations of radionuclides in air, food, and water at the receptors' locations. Alternately, samples of air, food, and water can be collected at the receptors' locations and analyzed. Either method uses the data gathered to calculate annual intakes and resulting doses. Licensees may use the MILDOS-AREA code to calculate dose to individuals and the general population from airborne radioactive material within an 80 km radius of an operating uranium recovery facility. The exposure pathways considered in MILDOS-AREA are inhalation;

external exposure from groundshine and cloud immersion; and ingestion of vegetables, meat, and milk (NRC 1981). Uranium particulates should be assumed to be insoluble—i.e., ICRP Class Y for radiological monitoring—because Class Y compounds have the highest dose conversion factors (Sv per Bq inhaled). The use of MILDOS-AREA as the sole method to demonstrate compliance with public dose limits is not acceptable to the NRC.

A generic CSM for human receptors, provided in Figure E-2, was developed based on information and figures available in Till and Grogan (2008). This CSM considers the transport of radiological and chemical contaminants through the terrestrial and aquatic environments. The CSM can be used by licensees to develop a site-specific CSM based on the type of uranium recovery facility and associated sources of exposure. The CSM illustrates the different environmental transport media, transfer routes and mechanisms, and human exposure pathways. The exposure pathways include inhalation, immersion, ingestion, dermal contact, and external radiation. The CSM reveals that human exposure can occur directly or indirectly via the food they consume.

Uranium recovery licensees should model their preoperational and, subsequently, operational processes via the conduct of a pathways analysis. Modeling radionuclide pathways is necessary to understand how a facility and its associated uranium recovery operation will impact the surrounding environs and radiation doses to the public.

Uranium recovery applicants should use the approach presented in Chapter 4 and this appendix, the Argonne National Laboratory RESRAD software codes, MILDOS-AREA, other equivalent informational sources (e.g., NRC RG 1.109 [NRC 1977]), computer codes, or some combination thereof, to evaluate any new routes of exposure contributing nominally more than 20% to the calculated individual dose. Use of the 20% value is designed to complement the guidance in NRC RG 4.1 applicable to monitoring in the environs of nuclear power plants. These informational sources and software tools can be utilized in the evaluation of risk-informed decisions.



Identifying new routes of exposure and including them in the sampling program could be implemented in the following way: MILDOS-AREA (or other approach acceptable to the NRC) could be used to rank each current sampling location from the highest to lowest concentration. If the land use census identified a new location that is above the lowest ranked concentration by 20%, this new location could be recognized as a viable new location and efforts made to include this new location into the program. (Values lower than 20% may result in locations being inserted into the sampling program unnecessarily.) A gradual phasing out of the lowest ranked concentration could then occur or the lowest ranked concentration retained in the program along with the new location.

In addition to citing principal and secondary radionuclides and pathways, the applicant should estimate quantities of radioactive material released to unrestricted areas and the subsequent projected dose to members of the public prior to operations. During operations, licensees should attempt to quantify the radioactive material released to unrestricted areas. Identifying which primary and secondary radionuclides and related pathways are associated with a facility's operations is necessary, but not sufficient for evaluating dose impacts to the public. The quantity of radioactive material released from the facility during the reporting period is also required to translate facility releases (e.g., in activity or concentration units) into applicable dose reporting units.

E.3.3. Required Monitoring

Criterion 7 of Appendix A to 10 CFR 40 requires licensees to conduct an environmental monitoring program to measure or evaluate compliance with applicable standards and regulations, to evaluate performance of control systems and procedures, to evaluate environmental impacts of operation, and to detect potential long term effects. Chapter 3 of this TBD specifically lists the monitoring requirements and recommendations for uranium recovery facilities, including stack sampling for particulates; air sampling of particulates and radon; and sampling of groundwater and surface water; vegetation, food and fish; soil and sediments; and direct radiation. The environmental media are required to be monitored for the presence of those radiological contaminants as described in Chapter 3.

Surface water and groundwater are the only environmental media of concern for the NRC that are monitored for non-radiological (chemical) contaminants per 10 CFR 40 Appendix A, Criterion 5 (Table 5C), Criterion 7A and Criterion 13, which provide groundwater protection standards, as imposed by the EPA in 40 CFR 192. Also, NUREG-1569 (NRC 2003) in Section 2.7, Table 2.7.3-1, includes a summary of typical water quality indicators to be determined during preoperational data collection at ISR facilities (this table was incorporated in this TBD as part of Chapter 3). This table is applicable for the other two types of uranium recovery facilities.

With the exception of the direct radiation pathway, other media types are relevant to the determination of internal dose. In addition, adequate meteorological data, as well as hydrological and geological data, are required to conduct the pathway analyses. These must be obtained during the preoperational monitoring phase, as they provide data to support the choice of sampling locations for various media.

In the operational monitoring phase, the environmental monitoring program will, for the most part, be a continuation of the preoperational monitoring program and may include sampling modifications as appropriate to address any changes in facility operations or land use particularly at locations where residents, recreational users, or intermittent occupants could be potentially affected. This is especially important for ISR facilities because of possible land use within the licensed area. One purpose of the environmental monitoring program is to demonstrate that the environmental monitoring program provides adequate data to verify compliance with applicable regulatory requirements. Another purpose is to verify that pathway analyses used to calculate radionuclide doses to members of the public are appropriate, and if not exact, at least conservatively determined to overestimate the doses received.

E.3.3.1. Radionuclides of Interest

The radionuclides of interest in particulate emissions from uranium mills include natural uranium, Th-230, Ra-226, and Pb-210. The IAEA (2002) also includes Po-210 in this listing. The ingestion pathway is a potentially significant contributor to dose due to the ingrowth of Po-210 from Pb-210 in the meat pathway. Uptake of elemental polonium from the soil also occurs readily by many plants and can then be ingested by animals. Therefore, the food ingestion pathway for Po-210 may be significant from a potential radiation dose perspective. Although Po-210 at ISR facilities does not follow dissolved uranium (will not enter into the process stream from the ore body), Po-210 may be drawn (via groundwater contamination) into an ISR facility located in close proximity to a conventional mill.

Pb-210, the precursor to Po-210 in the uranium series, is a beta emitter but also emits a low-energy gamma ray at 47 keV. The remaining radionuclides are alpha emitters, though a variety of gamma and x-ray emissions occur during the radioactive decay process. Consequently, analytical methods include gamma ray and x-ray spectrometry using HPGe detectors, or radiochemical separation followed by alpha or beta counting. Ra-226 emits a gamma ray at 186 keV which is difficult (but not impossible) to resolve from the 185 keV gamma ray emitted by U-235. Ra-226 may be measured by the radon emanation method, in which its first decay product, Rn-222, is collected and counted; however, this method is outdated. A better way is to measure Ra-226 directly by alpha spectrometry or to measure the progeny Pb-214 and/or Bi-214 by gamma ray spectrometry. Gamma spectrometry requires relatively little sample preparation, but in general, chemical separation is much more specific for the analyte than gamma spectrometry and thus offers less (potential) interferences.

For gaseous emissions, Rn-222 and its short-lived progeny (Po-218, Pb-214, Bi-214, and Po-214) require monitoring as the contribution from radon and progeny at uranium recovery facilities will often be the largest contributor to dose. Rn-222 is monitored by a variety of methods, including charcoal canisters (a short-term effort typically conducted over 1 to 7 days), alpha track detectors (typically a long term effort ranging from one to several months), or grab sampling followed by measurements of its progeny (a very quick, short-term effort often conducted in 30 minutes or less). While established protocols exist, environmental measurements of Po-218, Pb-214, Bi-214, and Po-214 are complicated because of their short radiological half-lives. Consequently, most facilities monitor for Rn-222 and assume the concentrations of the progeny are in a defined degree of equilibrium with Rn-222. An assumption of 100% equilibrium is conservative for dose assessment purposes. However, licensees may use a lower equilibrium factor if supported by adequate data.

Radon monitoring methods and reporting are currently being evaluated by NRC staff, especially with regards to licensee's meeting regulatory limits established in 10 CFR 20, Appendix B, Table 2. Chapter 3 also discusses the radon and radon progeny issue and its relevance to the public dose limits.

E.3.3.2 Radionuclides Not Requiring Monitoring

A pathway analysis supported by physical measurements and sample collection can be used by the licensee to support the elimination or reduction in the monitoring frequency of radionuclides that are either primary (e.g., U-235) or secondary to the process (radioactive progeny of the uranium series). Some examples include the following: while uranium must be monitored, isotopic analysis of uranium is not required, because the dose coefficients (mrem per pCi of intake) for U-234, U-235, and U-238 are quite similar (EPA 1988). Th-234 and Pa-234m have short radiological half-lives and could be separated from their parent, U-238, in the refining process. However, Th-234 and Pa-234m will reach equilibrium relatively quickly and, thus, can be assume to be in equilibrium with U-238.

The licensee should justify the elimination or reduction in the monitoring frequency of radionuclide(s) that do not significantly contribute to the dose to members of the public. The justification should use the NRC's license amendment process as a basis.

Once the radionuclides of interest have been established by the licensee and approved by NRC staff on a facility-specific or license-specific basis, a reduction or elimination in the radionuclides to be monitored must be defended. The license amendment process provides a vehicle to document the request.

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ATTACHMENT E- I. CHEMICAL TOXICITY OF URANIUM

E-I.1. URANIUM INTAKES

Although uranium has long been known to be chemically toxic, with the kidney being the primary affected organ, there is still no clearly established level for acute toxicity in humans (Kathren and Burklin 2008). Depleted, natural, and low-enriched (i.e., < 5% ^{235}U by weight) uranium are acknowledged to present higher chemical than radiological toxicity hazards; that is, the air concentrations established to prevent chemical toxicity from chronic exposure to soluble compounds of uranium in footnote 3 to Appendix B of 10 CFR 20 are lower than the radiologically-derived air concentrations given in the Appendix B table entry for uranium.

E-I.1.1. Chemical Form and Solubility of "Yellowcake"

The relative toxicity of uranium compounds is a function of their solubility in lung fluids (for inhalation intakes) or in the gastrointestinal (GI) tract (for ingestion intakes). In NUREG-0874 (NRC 1986), the NRC classified four types of uranium compounds: ore dust (UO_2) with particle sizes (AMAD—activity median aerodynamic diameter) of 1 micron or 10 microns; and uranium oxide products (usually called yellowcake, even though they are typically a mixture of uranium oxides, primarily UO_3 and UO_4, ammonium diuranate, and a small amount of U_3O_8) that are dried at low temperatures (low-temperature dried, or LTD) or at high temperatures (high-temperature dried, or HTD). The dividing line between the two is a drying temperature of 400° C. Ore dust and HTD materials are considered to be insoluble, and LTD materials are considered to be soluble. For in situ recovery facilities, there are no exposures to ore dust, and so the solubility classification of the product is solely a function of the drying temperature. Consequently, for LTD material, the limiting concentration is the chemical toxicity limit, while for HTD material and ore dust, the limiting concentration is the radiological derived air concentration (DAC) given in Appendix B to 10 CFR Part 20.

E-I.1.2. Chemical Toxicity Limits

A number of limits for uranium intake related to chemical toxicity have been established for various endpoints. The Occupational Safety and Health Administration (OSHA) sets a permissible exposure level of 0.05 mg m^{-3} time-weighted average (TWA) for soluble uranium, 0.25 mg m^{-3} TWA for insoluble compounds, and a short-term exposure level (STEL) of 0.6 mg m^{-3} for insoluble compounds (ATSDR 1999). The NRC limits weekly intakes to 10 mg soluble uranium in 10 CFR 20.1201(e), which corresponds to an average air concentration of 0.2 mg m^{-3}, which is also the maximum permissible air concentration for soluble uranium listed by the NRC in 10 CFR 20 Appendix B, footnote 3. The 0.2 mg m^{-3} level is traceable to a no adverse effects level (NOAEL) of 3 μg U per g kidney, or a kidney content of 0.93 mg uranium (note: the reference kidney mass is 310 g, so the NOAEL is 930 μg). A revised NOAEL has been suggested at 1.1 μg U per g kidney, or a kidney content of 0.337 mg uranium (Rich et al. 1988). The suggested maximum non-lethal value is only twice this level, or 0.67 mg U, and the suggested median lethal dose (LD_{50}) is fifty times the NOAEL, or 16.8 mg U in the kidney (Rich et al. 1988). The NRC, in 10 CFR 70.61, defines as a high-consequence event an acute uranium intake of 30 mg or more of soluble uranium, which would result in a maximum kidney content of 1.6 mg U following inhalation. The value of 30 mg acute intake is therefore appropriate for low-temperature dried yellowcake.

E-I.1.3. Derivation of Chemical Risk from Uranium Intakes

For chronic intakes, the equilibrium kidney burden should be maintained less than or equal to the NOAEL of 0.93 mg (3 μg U per g kidney). According to calculations in NUREG-0874, the equilibrium kidney burden for LTD material is 0.85 μg per 1 μg uranium inhaled daily, and so the NOAEL would be produced by a daily intake of 1.1 mg. For an 8-hour day at a breathing rate of 1.2 m^3 hr^{-1}, the resulting air concentration is 0.11 mg m^{-3}, which is reasonably close to the OSHA limit of 0.05 mg m^{-3}. The difference between this value and the value of 0.2 mg m^{-3} from 10 CFR 20.1201 is that the latter assumes a mixture of both highly soluble and moderately soluble materials; i.e., inhalation classes D and W as opposed to the more insoluble class Y.

However, for public exposures, permissible airborne concentrations must be lowered to account for continuous exposure, and the average breathing rate must also be adjusted. The World Health Organization (WHO) has published an exposure guideline for chemical toxicity to members of the public of a tolerable intake value of 0.5 μg per kg of body weight per day. For an adult, this intake level would be produced by air concentration of 1 μg m^{-3} (WHO 2003).

Consequently, downwind airborne concentrations of uranium monitored for compliance with radiological limits should be compared to this value for chemical toxicity. If the licensee can demonstrate that the solubility of the uranium released is less than that assumed for pure Class D, then this limit could be adjusted upwards accordingly. It should also be noted, however, that for children the limit would be scaled downwards by the ratio of body weight to that of an adult (70 kg).

A scenario modeled for public exposures to uranium in an accident situation indicate that for a very conservative scenario of a spill of almost 5,000 kg of uranium oxide product that is allowed to dry and become airborne without remediation, the NOAEL could be exceeded at distances of 100 m downwind from the spill for release periods exceeding 7 hours, and the acute toxicity limit exceeded for release periods exceeding 11 hours (ORISE 2011). Given typical land use around conventional mills and heap leach facilities, public exposures to uranium releases are unlikely to exceed chemical release limits; however, exposures to nearby members of the public from in-situ recovery facilities could exceed chemical toxicity limits under accident conditions, but not routine releases.

Licensees may also demonstrate compliance with chemical toxicity limits by using data on uranium concentrations in air gathered for radiological monitoring; to demonstrate compliance with radiological limits, an insoluble form of uranium is assumed, and to demonstrate compliance with chemical toxicity limits, a highly soluble (Class D) form of uranium is assumed. As an example, the potential chemical risk for the air emission limit in Table 2 of Appendix B of 10 CFR 20 can be calculated as follows.

By definition, the release limit for all isotopes of uranium, equal to 6×10^{-14} µCi/mL equates to a dose of 50 mrem to a member of the public. This dose can be converted to an intake by dividing it by the dose conversion factor for Class Y uranium in Federal Guidance Report 11 (EPA 1988). To be conservative, we use the dose conversion factor for U-238 of 3.2×10^{-5} Sv/Bq, which is slightly lower than the coefficients for the other isotopes, and so produces a higher intake value. First, the coefficient in Sv/Bq is multiplied by 3.7×10^{9} to convert the units to mrem/µCi, yielding 1.2×10^{5} mrem/µCi. Dividing 50 mrem by 1.2×10^{5} mrem/µCi, we get an intake of 4.2×10^{-4} µCi. Dividing this by the specific activity of U-nat, equal to 0.677 µCi/g, we get an intake of 0.62 mg per year, or 1.7 µg/day. If this were Class D uranium, the equilibrium kidney burden would be 1.4 µg, far below the NOAEL.

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