DIVISION OF DECOMMISSIONING, URANIUM RECOVERY, AND WASTE PROGRAMS INTERIM STAFF GUIDANCE DUWP-ISG-01

EVALUATIONS OF URANIUM RECOVERY FACILITY SURVEYS OF RADON AND RADON PROGENY IN AIR AND DEMONSTRATIONS OF COMPLIANCE WITH 10 CFR 20.1301

Final Report

Published June 2019

Division of Decommissioning, Uranium Recovery, and Waste Programs
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

U.S.NRC
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Protecting People and the Environment

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#Regulatory Analysis only

HISTORY OF THIS GUIDANCE

The U.S. Nuclear Regulatory Commission (NRC) staff is publishing this final Interim Staff Guidance for use. NRC staff published an initial draft for public comment on November 21, 2011 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML112720481). NRC staff considered the comments in preparing a revised draft report, published for public comment on March 27, 2014 (ML13310A198, *Federal Register* Notice at 79 FR 17194). The NRC staff then considered the public comments on the revised draft in preparing this final report. A summary of the public comments on the revised draft and NRC staff responses is available (ML15051A003).

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EXECUTIVE SUMMARY

In order to demonstrate compliance with the public dose limit of 100 mrem/yr in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 20, "Standards for protection against radiation," uranium recovery facility licensees must perform surveys of radioactivity in effluents to determine doses to members of the public. Radon-222 (radon) and its progeny are the most significant contributors to public dose at many uranium recovery facilities.[1] The dose from radon progeny is much greater than the dose from the radon itself.

The U.S. Nuclear Regulatory Commission (NRC) staff reviewed environmental monitoring reports from the existing uranium recovery licensees. These reports describe environmental radon monitoring results and, in some cases, evaluations of compliance with the 10 CFR Part 20 public dose limit. NRC staff recognized that NRC guidance on radon and radon progeny surveys and determining public dose for uranium recovery facilities needed to be clarified. Therefore, NRC staff prepared this Interim Staff Guidance (ISG) on radon and radon progeny surveys and certain aspects of dose determinations for uranium recovery facilities, to assist applicants, licensees, and NRC staff in evaluating compliance with the 10 CFR Part 20 public dose limit.

This ISG includes discussion and guidance on the following topics:

- the NRC's 1991 final rule "Standards for Protection Against Radiation," which indicates that uranium recovery facilities *must* consider the dose from radon progeny (56 FR 23360, 23374; May 21, 1991);
- methods for compliance with 10 CFR 20.1301 and 20.1302;
- survey methods for radon in air;
- aspects of measurements of environmental radon in air;
- a simple dose calculation method;
- radon progeny equilibrium factor; and
- other related aspects of demonstrations of compliance.

Section 5 of this ISG provides a summary of key points that NRC staff should address in performing technical reviews of licensee submittals (through licensing actions) and programs (through inspections).

1 BACKGROUND

Based on a review of recent submittals to the NRC, NRC staff determined that the agency's guidance regarding surveys of radon and radon progeny and determinations of dose to members of the public from operations of licensed uranium recovery facilities needed clarification.

[1] As discussed in Section 1, in this Interim Staff Guidance, "radon" refers to the isotope radon-222.

Notes on Applicability

This ISG is intended for NRC staff use when performing reviews of uranium recovery licensee[2] surveys of radon-222 (Rn-222) and Rn-222 progeny in air to demonstrate compliance with the public dose limit of 10 CFR 20.1301, "Dose limits for individual members of the public." This guidance also may be used in NRC staff evaluations of portions of uranium recovery facility license applications, renewals, or amendments dealing with Rn-222 and Rn-222 progeny surveys and associated determinations of dose to members of the public. Thus, this ISG should be used by NRC staff in evaluations supporting inspections and licensing actions for uranium recovery facilities. Since this ISG is focused only on compliance for Rn-222 and Rn-222 progeny in air, staff reviewers should refer to other documents for guidance on other aspects of compliance demonstrations. This ISG may be used by Agreement State staff in similar reviews, as appropriate.

This ISG applies directly to licensed uranium recovery facilities, which extract or concentrate uranium from ore processed primarily for its source material content. Uranium recovery facilities include in-situ recovery (ISR) facilities, conventional uranium mills, and heap leach facilities. Uranium recovery facilities are sources of radon and radon progeny because their operations involve or have involved processing of uranium ore. This ISG is applicable from initial licensing through decommissioning, but is not applicable to facilities after termination of the specific license (i.e., not applicable to sites under general license under 10 CFR 40.28).

NRC staff may consider use of parts of this ISG for reviews related to other types of facilities for which radon is a major effluent. NRC staff should evaluate such use on a case-by-case basis.

This ISG Provides Guidance

The NRC issues ISGs to clarify or to address issues not discussed in a Standard Review Plan (SRP). This ISG is not a substitute for NRC regulations, and compliance with it is not required. The ISG describes approaches that are acceptable to NRC staff. However, methods and approaches different from those in this ISG will be acceptable if the licensee provides an acceptable basis for concluding that its operations are in compliance with NRC regulations.

Uranium recovery facility licensees are required to perform surveys of radiation levels in unrestricted and controlled areas, and to perform surveys of radioactive materials in effluents released to unrestricted and controlled areas to demonstrate compliance with the dose limits for individual members of the public provided in 10 CFR 20.1301.

Regulations in 10 CFR 20.1301, "Dose limits for individual members of the public," and 10 CFR 20.1302, "Compliance with dose limits for individual members of the public," allow alternatives to demonstrate compliance with the public dose limit. This guidance addresses demonstrations of compliance with the public dose limit of 10 CFR 20.1301 for Rn-222 and Rn-222 progeny released from uranium recovery facilities.

In this document, the term "radon," without specifying the isotope, means Rn-222, since that is generally the isotope of concern for currently-licensed uranium recovery facilities. Radon progeny are addressed because most of the dose to people from radon releases is actually due

[2] In this document, the term "licensee" is used to refer to licensees and to applicants for licenses, as appropriate.

to exposure to the progeny. Radon progeny refers to the short-lived (half-lives less than one-half hour) decay products of Rn-222, which are polonium-218 (Po-218), lead-214 (Pb-214), bismuth-214 (Bi-214), and polonium-214 (Po-214). Although this ISG uses the term "radon progeny," other (especially older) documents may use the term "radon decay products" or "radon daughters" to refer to the same short-lived decay products of radon.

Although this ISG is not directly applicable to radon-220, some of the technical guidance in the ISG may be useful for surveys of radon-220. NRC staff should evaluate licensee submittals involving radon-220 on a case-by-case basis.

This ISG is *not* intended to provide a primer on radon and radon progeny in the environment. Some selected useful sources of basic information about radon and radon progeny are listed below.

Sources of Basic Information on Radon and Radon Progeny	
Topic	**References**
Basics of radon and progeny: fundamental physics, in-growth, decay.	Evans 1969, Jenkins 2010, NCRP 1988.
Textbooks (note that focus is on radon in indoor air)	Nazaroff and Nero 1988, Cothern and Smith 1987.
Radon decay scheme	NCRP 1988.
Measurements of radon and radon progeny	NCRP 1988, George 1996, George 2005, Maiello and Hoover 2010 (Method 8).
Measured equilibrium factor	Wasiolek and Schery 1993, Wasiolek and James 1995.
Exposure, dosimetry, risk, epidemiology	NCRP 1984a, NCRP 1984b, NCRP 1988, NCRP 2009, ICRP 1993, ICRP 2010, UNSCEAR 1993, UNSCEAR 2000, UNSCEAR 2006, Marsh *et al*., 2010, Field *et al*., 2000.
Radon aspects of Statements of Consideration (SOC) for 1991 update of 10 CFR Part 20	*Federal Register* (56 FR 23360; May 21, 1991), specifically pages 23374, 23375, and 23387.

The remaining sections of this ISG include:

- regulatory requirements and applicable guidance (Section 2)
- overview of compliance with the public dose limit of 10 CFR 20.1301 (Section 3)
- guidance on detailed technical aspects of surveys and compliance with the NRC public dose limit (Section 4)
- summary of key points for technical reviews (Section 5)
- references (Section 6)

2 REGULATORY REQUIREMENTS AND GUIDANCE

NRC staff reviewers should be familiar with the following relevant regulatory requirements and guidance.

Regulatory Requirements	
10 CFR 20.1001	Purpose
10 CFR 20.1003	Definitions
10 CFR 20.1101	Radiation protection programs
10 CFR 20.1301	Dose limits for individual members of the public
10 CFR 20.1302	Compliance with dose limits for individual members of the public
10 CFR 20.1501	Surveys and monitoring: general
10 CFR Part 20, Appendix B	Annual Limit on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage
10 CFR 40.65	Effluent monitoring reporting requirements
10 CFR Part 40, Appendix A	Criterion 7: regarding preoperational and operational monitoring programs Criterion 8: regarding keeping airborne effluent releases as low as is reasonably achievable (ALARA)

Regulatory Guidance	
Regulatory Guide 3.51[3]	Calculational Models for Estimating Radiation Doses to Man from Airborne Radioactive Materials Resulting from Uranium Milling Operations (March 1982a)
Regulatory Guide 3.59[3]	Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations (March 1987)
Regulatory Guide 4.14[3]	Radiological Effluent and Environmental Monitoring at Uranium Mills (Revision 1, April 1980)
Regulatory Guide 4.15	Quality Assurance for Radiological Monitoring Programs (Inception through Normal Operations to License Termination) — Effluent Streams and the Environment (Revision 2, July 2007)
Regulatory Guide 4.20	Constraint on Releases of Airborne Radioactive Materials to the Environment for Licensees Other than Power Reactors (Revision 1, April 2012)
Regulatory Guide 8.37	ALARA Levels for Effluents from Materials Facilities (July 1993)
NUREG-0859	Compliance Determination Procedures for Environmental Radiation Protection Standards for Uranium Recovery Facilities 40 CFR Part 190 (March 1982b)
NUREG-1569	Standard Review Plan for In Situ Leach Uranium Extraction License Applications (Final Report, June 2003)
NUREG-1620	Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act of 1978 (June 2003)
NUREG-1736	Consolidated Guidance: 10 CFR Part 20 — Standards for Protection Against Radiation (October 2001)
NUREG-2126	Standard Review Plan for Conventional Uranium Mill and Heap Leach Facilities – Draft Report for Comment (November 2014)

3 OVERVIEW OF METHODS FOR DEMONSTRATING COMPLIANCE WITH 10 CFR 20.1301

Licensees must demonstrate compliance with 10 CFR 20.1301, as specified in 10 CFR 20.1302:

> 10 CFR 20.1302
>
> (a) The licensee shall make or cause to be made, as appropriate, surveys 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.

[3] Certain sections of the guidance included in Regulatory Guides 3.51, 3.59, and 4.14 are outdated and no longer consistent with 10 CFR Part 20. However, the portions of these Regulatory Guides referenced and used in this ISG comply with 10 CFR Part 20 requirements.

(b) A licensee shall show compliance with the annual dose limit in § 20.1301 by—

(1) Demonstrating by measurement or calculation that the total effective dose equivalent to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit; or

(2) Demonstrating that—

(i) The annual average concentrations of radioactive material released in gaseous and liquid effluents at the boundary of the unrestricted area do not exceed the values specified in table 2 of appendix B to part 20; and

(ii) If an individual were continuously present in an unrestricted area, the dose from external sources would not exceed 0.002 rem (0.02 mSv) in an hour and 0.05 rem (0.5 mSv) in a year.

(c) Upon approval from the Commission, the licensee may adjust the effluent concentration values in appendix B to part 20, table 2, for members of the public, to take into account the actual physical and chemical characteristics of the effluents (e.g., aerosol size distribution, solubility, density, radioactive decay equilibrium, chemical form).

For either of the two basic compliance methods, 10 CFR 20.1302(b)(1) or 10 CFR 20.1302(b)(2), licensees must address doses from all radionuclides of concern and for the most exposed individual members of the public. If the compliance method of 10 CFR 20.1302(b)(1) (dose assessment) is used, licensees must address all pathways of exposure. For uranium recovery facilities, in most cases exposure pathways will include inhalation of radon and radon progeny, inhalation of uranium and other radionuclides in particulate form, and direct (gamma) radiation exposure. However, in some cases, other exposure pathways (e.g., ingestion of vegetables or meat from animals or ingestion of ground water contaminated from plant operations) should also be included if they contribute significantly to dose. As stated in Regulatory Guide (RG) 4.14, an exposure pathway should be considered to contribute significantly to dose if the predicted dose to an individual would exceed 5% of the applicable radiation protection standard.

Regardless of which compliance method is used, licensees must also address all sources, including point and diffuse or area sources, of radiation and radioactive effluents. Typical sources of effluents are described in RG 3.59 (NRC 1987) and Appendix D of NUREG-1569 (NRC 2003). However, in some cases, there may be unique situations resulting in additional sources of effluents. One example is the land application of water as a method for disposing of excess water from the production bleed at ISR facilities; other site-specific disposal practices may also exist. Staff reviewers should evaluate whether licensees have addressed all sources of radiation and radioactive effluents that have an impact on individual members of the public.

This ISG provides additional guidance about accounting for exposure and dose from radon progeny (the short-lived progeny). The radon progeny will be the principal contributor to radiation dose in most practical radon exposure situations (including at uranium recovery facilities). Therefore, determinations of radon doses to the public must include the dose from radon progeny. See Section 4.7.1 and Appendix 1 of this guidance for more detail on the need to account for radon progeny dose. (Lead-210 and polonium-210, which are not considered among the short-lived radon progeny, may need to be evaluated separately; this guidance does not address evaluations of Pb-210 and Po-210.)

3.1 Compliance with 10 CFR 20.1301/1302 by Comparison to 10 CFR Part 20, Appendix B, Effluent Concentration Values

The licensee may comply with 10 CFR 20.1301 by demonstrating that concentrations in air at the boundary of the unrestricted area are no greater than the 10 CFR Part 20, Appendix B, Table 2, "Effluent Concentration," value for radon-222 with daughters (progeny) present. Surveys of radon concentrations in air should be performed as described later in this document. See Section 4.11 of this guidance for detailed information on this compliance method.

This ISG generally expresses concentrations of radon in air in units of pCi/L as these units are commonly used. However, the effluent concentration values in 10 CFR Part 20, Appendix B, Table 2, are provided in units of µCi/mL. To convert, multiply units of pCi/L by 1×10^{-9} to obtain units of µCi/mL (e.g., 0.1 pCi/L = 1×10^{-10} µCi/mL).

3.2 Compliance with 10 CFR 20.1301/1302 by Performing Dose Assessment

The licensee may comply with 10 CFR 20.1301 by demonstrating that the dose (total effective dose equivalent (TEDE)) to the individual likely to receive the highest dose from the licensed operation does not exceed 100 mrem/yr. Licensees need to provide the justification for assumptions about the radon and radon progeny equilibrium, the dose conversion factor, and other parameters used to determine the dose estimate. See Section 4.12 of this guidance for detailed information on this compliance method.

3.3 Transparency and Documentation of Compliance with 10 CFR 20.1301/1302, Licensee Information to Be Reviewed

Licensees must demonstrate compliance with the public dose limit of 10 CFR 20.1301 (i.e., addressing contributions from effluents and external sources of radiation) annually. Thus, NRC staff expects that licensee demonstrations of compliance with the public dose limit will be performed on an annual basis and that the NRC staff will evaluate compliance on an annual basis either during inspections or during NRC staff reviews of required reports. Licensees should periodically evaluate their dose compliance throughout the year at the frequency of their sampling regimes (for example, if data is collected quarterly then at each quarter the licensee should evaluate the data obtained up to that time) to ensure that licensees are managing releases and direct radiation from their operations consistent with ALARA principles.

10 CFR 20.2107 requires licensees to maintain records sufficient to demonstrate compliance with the public dose limit described in 10 CFR 20.1301, but does not require licensees to submit such records to the NRC. However, some licensees may be required by license condition to submit information about the determinations of dose to members of the public to the NRC. Other licensees voluntarily submit the demonstration of compliance in different types of reports, including annual ALARA audit reports or as part of the semi-annual effluent report (also known as "40.65 reports," based on 10 CFR 40.65, "Effluent monitoring reporting requirements") for the second half of the year.

NRC staff reviewers should not rely solely on reports of annual public dose or semi-annual effluent reports for all information related to potential doses to members of the public. NRC staff reviewers, including inspectors, should ensure that they are evaluating the licensee's official annual public dose compliance documentation before beginning their evaluations. Staff reviewers should obtain a general knowledge of processes at the site, especially related to the sources of radiation, effluent pathways at the site, waste disposal methods, and sampling methods. NRC staff reviewers should review the licensing basis (e.g., license, specific license application commitment, license condition, or licensee submittal in response to license condition). NRC staff reviewers should also review original documentation of measurements, such as laboratory and sample analysis reports.

NRC staff reviewers should evaluate whether licensees have completely documented the assessments performed to show compliance. Licensees should provide a complete assessment of the dose to members of the public, with sufficient documentation that NRC staff can independently replicate the assessment. Specifically, a licensee should, at a minimum, clearly address or reference:

- the method it used to demonstrate compliance, including accounting for radon progeny;
- its evaluation of which member of the public is the individual likely to receive the highest dose from licensed operations; description of location for compliance demonstration for the individual likely to receive the highest dose;
- how it considered all sources of radiation, residual radioactivity, and radioactive material in effluents under the control of the licensee;
- how it considered doses from all pathways of exposures;
- its results or the doses determined for members of the public;
- the land use census (survey) to verify existing receptors and exposure pathways as well as identify potential new receptors and exposure pathways;
- the measurement methods, sampling frequency, minimum detectable concentrations, and results of measurements, with associated uncertainties;
- its choices of parameter values and all assumptions, with the technical basis;
- maps clearly identifying the location of monitoring stations including background stations, licensed areas, restricted areas, unrestricted areas, controlled areas, nearest resident, and meteorological sectors, as appropriate, for the dose compliance assessment;
- the meteorological data, if used, to determine monitoring locations or to calculate air transport of radionuclides;
- its comparison of results to the regulatory requirements; and
- any comparisons of results with previous reporting periods to identify trends (although not required by regulations).

4 CONDUCTING A TECHNICAL REVIEW OF RADON COMPLIANCE ASSESSMENTS

NRC staff reviewers should ensure that licensees address doses from all pathways of exposures and for the individual likely to receive the highest dose. In most cases, exposure pathways will include inhalation of radon and radon progeny, inhalation of uranium and other radionuclides in particulate form, and direct (gamma) radiation exposure (reviewers should note that only radon and radon progeny are discussed in this present document). In some cases, other exposure pathways (e.g., ingestion of meat from animals or ingestion of ground water contaminated from facility operations) must be considered if there is a significant pathway to exposure of people (see RG 4.14, which states an exposure pathway should be considered important for environmental monitoring (measurements) if the predicted dose to an individual would exceed 5% of the applicable radiation protection standard).

NRC staff reviewers should consider the following regulatory requirements in 10 CFR Part 20 that pertain to public dose limits, the limit on dose rates from external sources in unrestricted areas, and the dose constraint for airborne effluents:

- 10 CFR 20.1301(a)(1) requires in part that the TEDE does not exceed 100 mrem (1 mSv) in a year to individual members of the public from licensed operations exclusive of contributions from background radiation;
- 10 CFR 20.1301(a)(2) requires in part that doses from external sources do not exceed 2 mrem (0.02 mSv) in any one hour in any unrestricted area;
- 10 CFR 20.1301(b) requires that doses to members of the public allowed access by the licensee to controlled areas do not exceed 100 mrem/yr (1 mSv/yr);
- 10 CFR 20.1101(b), in part, requires licensees to use, to the extent practical, procedures and engineering controls to achieve doses to members of the public that are as low as is reasonably achievable (ALARA);
- 10 CFR 20.1101(d) requires licensees to establish a constraint on air emissions such that individual members of the public likely to receive the highest dose will not be expected to exceed a TEDE of 10 mrem/yr (0.1 mSv/yr) from air emissions of radioactive material excluding radon-222 and its daughters (progeny); and
- 10 CFR 20.1301(e) specifies that licensees subject to the U.S. Environmental Protection Agency's (EPA's) generally applicable environmental radiation standards in 40 CFR Part 190, "Environmental radiation protection standards for nuclear power operations," must comply with those standards. Section 190.10(a) of Title 40 of the Code of Federal Regulations specifies that the annual dose equivalent must not exceed 25 mrem (0.25 mSv) to the whole body, 75 mrem (0.75 mSv) to the thyroid, and 25 mrem (0.25 mSv) to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters (progeny) excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations. NRC staff should understand that EPA's dose limits are in terms of dose equivalent. This is different from the NRC public dose limit (10 CFR 20.1301), which is in terms of total effective dose equivalent (TEDE).

NRC staff reviewers should ensure that licensees have evaluated which members of the public are likely to be the most highly exposed because of licensed operations. If a licensee allows public access to controlled areas of the facility, it also needs to demonstrate that the dose to these members of the public does not exceed the 10 CFR 20.1301 limit. NRC staff notes that some licensees provide onsite residences for workers; while off-duty, these people are considered members of the public.

The public dose limit is a limit on the TEDE to members of the public from licensed operations, and doses may be received in multiple locations. Thus, the compliance assessment must include an evaluation of radon and progeny in locations where receptors are exposed. For example, for residents near a facility who spend time in their homes, the assessment needs to address indoor exposure to radon and radon progeny from licensed operations. A method to address indoor exposure is described in Section 4.2.1 of this ISG.

Although the NRC regulations do not specifically require licensees to evaluate trends in their effluent quantities or public doses, NRC staff reviewers should evaluate potential trends in these quantities, because trends may provide indications of improvements or degradations in performance (as related to changes in operations or measurement quality assurance, etc.). However, licensees are required to report effluent quantities that are significantly above their design basis objectives (10 CFR 40.65). NRC staff should consider compiling data submitted by licensees in previous years, plotting the data, and performing statistical tests of trends, as appropriate.

4.1 Overview of Surveys of Radon and Radon Progeny in Air

Compliance with 10 CFR 20.1301 and 10 CFR 20.1302 requires licensees to address radon and radon progeny. In demonstrating compliance with the public dose limit, 10 CFR 20.1302(a) requires licensees to survey radioactive materials in effluents released to unrestricted and controlled areas. In 10 CFR 20.1003, *survey* is defined as an evaluation of radiological conditions that includes measurements or calculations of levels of radiation or concentrations or quantities of radioactive material present.

As discussed below, NRC staff reviewers should ensure that uranium recovery licensee evaluations address radon and radon progeny. NRC staff should ensure that the licensee’s survey or dose assessment addresses the dose contribution from radon progeny (see also Section 4.11.1 and Appendix 1 for more detail).

The NRC does not intend this ISG to provide extensive information on monitoring methods. A useful general reference is the “Multi-Agency Radiological Laboratory Analytical Protocols Manual,” (MARLAP) (NRC 2004), which provides guidance for the planning, implementation, and assessment of projects that require the laboratory analysis of radionuclides.

4.2 Survey Approaches for Radon in Air

The option to perform measurements or calculations for surveys provides flexibility in methods for performing the radon surveys necessary for compliance with 10 CFR 20.1302. Four methods acceptable to NRC staff are summarized in the table below and described in more detail in the following subsections. These methods are considered adequate to demonstrate compliance with 10 CFR 20.1302. Other options to demonstrate compliance may be acceptable if supported by an adequate justification or technical basis.

It is current NRC staff practice that the use of models alone generally is insufficient for use in demonstrating compliance with 10 CFR 20.1301 and 20.1302. This practice is based on existing NRC guidance. RG 3.59 (NRC 1987) provides guidance on the use of predictive models to evaluate the potential impacts of prospective new operations when environmental monitoring data is not yet available. RG 3.59 provides guidance for the preparation of environmental reports and environmental impacts statements and the NRC staff review of those reports. For separate guidance on compliance with radiation protection standards, RG 3.59 refers specifically to NUREG-0859 (NRC 1982b). NRC staff recognizes that NUREG-0859 specifically addresses issues of compliance with the EPA’s generally applicable environmental radiation standards in 40 CFR Part 190, “Environmental radiation protection standards for nuclear power operations.” However, RG 3.59 refers to NUREG-0859 for guidance on compliance with radiation protection standards; radiation protection standards include 10 CFR 20.1301 and 20.1302. Thus, NRC staff has determined that the general concepts in NUREG-0859 are applicable to compliance with 10 CFR 20.1301 and 20.1302. NUREG-0859 states that compliance determinations during operations would be based on environmental monitoring data. Under 10 CFR 20.1003, monitoring is defined and refers specifically to measurements. Uranium recovery licensees also are required to meet 10 CFR 40, Appendix A, Criterion 7, which requires, in part, licensees to conduct operational monitoring programs to measure or evaluate compliance with applicable standards and regulations. Thus, the NRC staff concludes that monitoring data (measurements) generally should be the basis for demonstrations of compliance with 10 CFR 20.1301 and 20.1302.

Options 2 and 3 in the following table include substantial reliance on models for parts of the compliance evaluation. For these cases, NRC staff should ensure that the licensee has also made appropriate environmental or other measurements to confirm or compare to the model predictions, as described in Sections 4.2.2 and 4.2.3. Detailed guidance regarding use of modeling to demonstrate compliance and measurements to confirm or compare to such modeling is beyond the scope of this ISG. In some cases, licensees may have collected supplemental radon or radon progeny results, such as results from equilibrium studies or statistical evaluations of the facility's historical operational data obtained at different locations within the facility. Such information may aid in evaluating or supporting the licensee's conclusions about its dose compliance model predictions. However, NRC staff should evaluate the modeling and confirmation measurements on a case-by-case basis. When models are used, NRC staff should evaluate whether the level of justification for parameter values provided is commensurate with the significance of the parameter relative to the dose assessment results, as evaluated through sensitivity analyses.

Summary of Acceptable Methods for Surveys (Combined Measurements and Calculations) of Radon and Radon Progeny in Air for Compliance with 10 CFR 20.1302		
	Measurements	**Associated Calculations**
1 (see §4.2.1)	Measure radon concentration outdoors at the boundary of the unrestricted area or receptor location.	When appropriate for receptors that spend time indoors (e.g., at a residence), calculate indoor radon concentration.
2 (see §4.2.2)	Measure operational process parameters.	Calculate radon release rates. Then calculate the radon concentration at the unrestricted area boundary or receptor locations. Confirm or compare with measurements of radon in air.
3 (see §4.2.3)	Measure the radon released at vents or stacks by conventional stack monitoring, and measure the radon from wellfields, tailings, ore pads and storage areas, or heap-leach piles using passive or dynamic radon monitors.	Calculate the radon concentration at the unrestricted area boundary or receptor location. Confirm or compare with measurements of radon in air.
4 (see §4.2.4)	Measure radon progeny directly at receptor locations.	Convert to radon equivalent (see Section 4.13).

4.2.1 Measure Radon Outdoors at Unrestricted Area Boundary or Receptor Location

One approach to surveying radon in air is to measure radon concentration outdoors at the boundary of the unrestricted area or receptor location. If the compliance method used is comparing measured concentrations to the 10 CFR Part 20, Appendix B, Table 2, value (see 10 CFR 20.1302(b)(2)(i)), the measurements must determine concentrations at the boundary of the unrestricted area. If the compliance method used is to demonstrate that the dose to the individual likely to receive the highest dose (i.e., the receptor(s)) does not exceed the annual dose limits (see 10 CFR 20.1302(b)(1)), the licensee should measure radon concentrations near the receptor locations.

If receptors spend time indoors (e.g., at a residence), the licensee may calculate the indoor radon concentration. For assessment of residential exposures, radon concentrations outdoors and indoors may be important. For indoor concentrations, it may be difficult to distinguish the radon contributions of licensed operations from those of background contributions (especially background due to infiltration into a house from the underlying soil).

Schiager (1974) states that for buildings immediately adjacent to a tailings pile, the indoor radon concentration would be in equilibrium with (i.e., the same as) that found outdoors. This is a simplified model of infiltration of outdoor radon into buildings. Thus, measurements usually are made outdoors, and it is assumed that the indoor radon concentration due to licensee activities is equal to the outdoor concentration (at the same location) due to licensee activities (e.g., around the house). NRC staff considers it reasonable and acceptable to assume that the indoor radon concentration due to licensee activities is equal to the outdoor concentration due to licensee activities.

If a licensee chooses for any reason not to assume indoor concentrations are equal to outdoor concentrations, it may, for example, perform a more detailed analysis of the infiltration of outdoor radon into a residence based on the air exchange rate between outdoor and indoor air. Such an infiltration modeling method is briefly described in United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993). NRC staff expects that for most buildings with reasonable air exchange rates, this refinement would result in an estimated indoor radon concentration that is similar to assuming the indoor concentration equals the outdoor concentration.

4.2.2 Measure Operational Parameters to Calculate Radon Releases

Another approach to surveying radon in air is to measure uranium recovery facility operational process parameters. Based on these measured operational parameters, licensees could calculate a radon release rate or source term for vents, stacks, other release points, wellfields, tailings, ore pads and storage areas, and heap-leach piles. RG 3.59 (NRC 1987) and Appendix D of NUREG-1569 (NRC 2003) provide information on potential radon emission sources and guidance on methods that may be used for these calculations of emissions. NRC staff should ensure that all significant emission sources have been addressed and that calculations are appropriate. If a licensee (or applicant) bases radon releases on operational process parameters, NRC staff should ensure that the licensee also has made (or for applicants, commits to make) measurements to confirm the operational parameters.

Based on the calculated radon release rates, the radon concentration at the unrestricted area boundary or receptor locations can be calculated using standard atmospheric dispersion calculations or an appropriate computer code (such as MILDOS-AREA (see NUREG-1569, Section 7.3)). If computer codes are used, NRC staff should ensure that the licensee has used code versions that have been verified and benchmarked against similar models or codes, when practical. If such models are used for transport calculations, NRC staff should ensure that the licensee has measured (or the applicant commits to measuring) radon or radon progeny in air and modelled concentrations should be comparable to measured values or differences should be explained and understood. An example of such an approach is briefly discussed in Section 4.7.

4.2.3 Measure Radon in Stacks and Other Effluent Points

A third approach to surveying radon in air is to measure the radon released at vents or stacks by conventional stack monitoring, and measure the radon from wellfields, tailings, ore pads and storage areas, heap-leach piles, or other nonpoint sources using passive or dynamic radon monitors. NRC staff should ensure that all significant emission sources have been addressed (see RG 3.59 (NRC 1987) and Appendix D of NUREG-1569 (NRC 2003)) and that calculations are appropriate. Based on the measured radon release rates, the radon concentration at the unrestricted area boundary or receptor locations can be calculated using standard atmospheric dispersion calculations or an appropriate computer code (such as MILDOS-AREA (see NUREG-1569, Section 7.3)). If computer codes are used, NRC staff should ensure that the licensee has used code versions that have been verified and benchmarked against similar models or codes, when practical. If such models are used for transport calculations, NRC staff should ensure that the licensee has measured (or the applicant commits to measuring) radon or radon progeny in air and modelled concentrations should be comparable to measured values or differences should be explained and understood.

4.2.4 Measure Radon Progeny Concentration Directly

In some cases, it may be appropriate for licensees to measure radon progeny concentrations directly for use in determining compliance. One example is a case in which members of the public are visitors to a controlled or restricted area where the radon progeny concentration in air is high enough that it is practical to measure radon progeny concentrations directly. If this approach is used, the licensee would need to perform calculations (for comparison to the 10 CFR Part 20, Appendix B, Table 2, value or for a dose calculation) that are slightly different from those done based on measurements of radon concentration. These differences are noted in Section 4.13 of this ISG.

4.3 Background Radon Concentrations and Preoperational Monitoring:

NRC staff notes that establishment of background monitoring (locations and other aspects) is part of the technical licensing basis for some licensees. In these cases, changes to the background monitoring may require changes to the technical licensing basis and thus must be approved through the licensing process.

The public dose limit of 10 CFR 20.1301 specifically excludes dose contributions from background radiation. Thus, in surveying radon concentrations around facilities, NRC licensees may subtract the background radon levels from measured concentrations to determine net concentrations due to licensed activities. These net concentrations may be used in determinations of compliance with 10 CFR 20.1301/1302. Background concentrations generally should be averaged over a concurrent one-year period of time in order to be suitable for use in determining net concentrations for use in compliance demonstrations.

NRC staff should consider whether the facility has *unlicensed* radioactive material that may not be considered part of background radiation (and thus needs to be considered in meeting the public dose limit). In many cases, unlicensed radioactive material may be considered part of background radiation. However, some unlicensed radioactive material as well as radiation sources related to the licensed operations and under the control of the licensee, may need to be accounted for in the TEDE for compliance with the public dose limit of 10 CFR 20.1301. This is based on (1) the purpose of 10 CFR Part 20 (20.1001(b)); (2) the definition of public dose (10 CFR 20.1003); (3) the applicability in 10 CFR 20.1301(a)(1) to "licensed operations;" and (4) the Commission Memorandum and Order in *Hydro Resources, Inc.*, CLI-06-14, 63 NRC 510 (NRC 2006). The Memorandum and Order specifically points out that 10 CFR 20.1301(a)(1) uses the term "licensed operations," not "licensed materials." Thus, it is possible that some unlicensed material or other sources used in the licensed operations and under control of the licensee are subject to the public dose limit of 20.1301 and should *not* be considered part of background radiation. Staff should evaluate these situations on a case-by-case basis.

Establishing background locations for outdoor radon measurements is difficult in many situations. Typically, background locations are established upwind of facilities. However, determining appropriate background location(s) is complicated by spatially and temporally varying concentrations; impact of varying geology on the natural emissions of radon from soil into air; effects of topography on wind patterns, especially on patterns of low speed winds (e.g., down valley drainage); and potentially other nearby radon sources, particularly for sites located in heavily mined areas. Licensees should determine background locations on a case-specific basis. As stated above, to demonstrate compliance with 10 CFR 20.1301, measurements at the boundary of the unrestricted area or receptor locations and background locations should be made over a concurrent one-year period. However, preoperational monitoring may provide a more complete understanding of background radon concentrations. RG 4.14 recommends one year of preoperational monitoring. Annual average background radon concentrations outdoors may vary considerably year-to-year. Background radon concentrations also may vary spatially and preoperational monitoring can be very useful in determining when spatial variability may be significant relative to the proposed operational monitoring. In cases of substantial spatial variability in background concentrations, it may be useful to have multiple background locations to represent background concentrations for multiple areas of the facility or surroundings.

During operations, background measurements should be made during the same time period as the measurements around the facility when used directly for demonstrations of compliance with 10 CFR 20.1301. Background radon concentrations may exhibit substantial temporal variability, including both seasonal and longer-term (year-to-year) variability. Thus, background measurements will be most representative of the time over which they are measured. NUREG-1501 (NRC 1994b) provides a general discussion of variability in background radiation that may be useful to reviewers.

Since background monitoring should be performed concurrently with operational monitoring at the boundary of the unrestricted area or receptor locations, NRC staff reviewers should be aware of the complexities of determining an appropriate background outdoor radon concentration that is representative of the receptor (or other monitoring) locations. A background location typically would need to be close to the monitoring locations, with geology similar to the site geology, so that the background location is representative of the monitoring location. But the background location should also be far enough from the facility that the radon concentration is not significantly affected by radon releases from the facility. If onsite meteorological data are available, the data can be used to help determine if background locations are unimpacted or minimally impacted by site operations.

RG 4.14 provides guidance on numbers and locations of preoperational monitoring locations and recommends one year of preoperational monitoring. There may be conditions in which applicants or licensees may want to consider using more monitoring locations or a longer preoperational monitoring period than recommended (i.e., monitor for longer than four quarters) to provide a better understanding of the background radon concentrations and spatial and temporal variability around the proposed facility location. Such conditions include:

- the location is known to have elevated radon concentrations;
- the location has significant topographic features such as valleys, mountains, buttes, or varying elevations;
- there are significant existing sources of radon nearby; for example, old mine shafts, outcroppings of uranium-bearing minerals, or other uranium recovery facilities; or
- preliminary preoperational monitoring data or other existing data indicate substantial spatial variability in radon concentrations.

Monitoring for a longer pre-operational time period will provide more data and thus a stronger statistical basis for conclusions about differences in concentrations among monitoring locations. This may be especially important in cases where the apparent differences in concentrations exceed levels that might result in doses of 100 mrem/yr to a member of the public. NRC staff should evaluate the statistical basis, or independently perform its own statistical analysis, of licensee statements that true background concentrations are significantly different at different monitoring locations.

NRC staff should compare results of monitoring at background locations to other locations. NRC reviewers should evaluate cases in which radon concentrations measured at the background location are consistently higher than concentrations at or around (especially downwind from) the facility. This situation may be an indication of a background location that is influenced by other radon sources or in other ways is not representative of the true background radon concentrations for the facility.

4.4 Types of Radon Measurement Methods

The “Standard Review Plan for In Situ Leach Uranium Extraction License Applications” (NUREG-1569) refers to RG 4.14 for discussion of radon sampling methods. RG 4.14 recommends that samples for radon in air be collected continuously at the same locations, or for at least one week per month. Specific collection methods are not provided in RG 4.14.

This ISG does not provide information on all measurement methods. Typically, passive alpha-track detectors are used to measure environmental levels of radon and these devices have been used at most uranium recovery facilities. Other methods also may be used.

4.5 Uncertainty and Minimum Detectable Concentration

Licensees (and applicants) should document and NRC staff should evaluate the minimum detectable concentration (MDC) of devices, instruments, or methods used by licensees for demonstrating compliance with the public dose limit of 10 CFR 20.1301. For alpha-track detectors, the MDC is commonly given as a time-integrated concentration (i.e., an integrated product of concentration and time at that concentration; for example, in units pCi-days/L).

RG 4.14 recommends an MDC (termed lower limit of detection in that RG) for radon in air of 0.2 pCi/L. NRC staff notes that this RG was published before the 1991 update of 10 CFR Part 20, which reduced by a factor of 30 the Appendix B, Table 2, effluent concentration value for Rn-222. The RG also recommends that the uncertainty associated with sample analyses should always be calculated and should take into account all significant sources of uncertainty, not just the counting statistics uncertainty. The MDC of 0.2 pCi/L (recommended in RG 4.14) would be applicable to measurements of background concentrations and gross concentrations at potential receptor locations.

This MDC may be sufficient, but the uncertainty in net measured radon concentrations is also important. NRC staff notes that measurement uncertainty is distinct from variability (either temporal or spatial variability), though in some cases it may be difficult to separate measurement uncertainty from temporal variability. The NRC Health Physics Position 223 (HPPOS-223) discusses consideration of measurement uncertainty for compliance with regulatory limits (NRC 1994c). HPPOS-223 states:

> The NRC position is that the result of a valid measurement obtained by a method that provides a reasonable demonstration of compliance or of noncompliance should be accepted and that the uncertainty inherent in that measured value need not be considered in determining compliance or non-compliance with a regulatory limit. Thus, only the measured value (and not the sum of the measured value and its uncertainty) need be less than the value of the limit to demonstrate compliance with the limit. Conversely, only the measured value (and not the measured value less its uncertainty) need be greater than the value of the limit to demonstrate non-compliance with the limit.

As provided by the HPPOS-223 statement, the result of a valid measurement obtained by a method which provides reasonable demonstration of compliance is acceptable. To address whether the measurement method provides valid measurements and a *reasonable* demonstration, NRC staff should evaluate the licensee's determination of measurement sensitivity (e.g., MDC); uncertainty; and/or overall uncertainty in the licensee's calculations of net (i.e., due to licensed operations) radon concentrations, as appropriate. In evaluating uncertainty, NRC staff should use standard methods for propagating uncertainty; one source of guidance on measurement uncertainty evaluations is Chapter 19 of the MARLAP manual (NRC 2004). NRC staff and licensees should understand the importance of total uncertainty (and thus the propagation of uncertainty concepts), especially in certain cases such as those with concentrations that are low relative to the background concentration. The relative uncertainty in net radon concentration should be reasonable relative to the magnitude of the calculated doses.

RG 4.14 recommends that if actual concentrations of radionuclides being sampled are higher than the lower limits of detection recommended, the sampling and analysis procedures need only be adequate to measure the actual concentrations. RG 4.14 further recommends that in such cases the measurement uncertainty (one standard deviation) should be no greater than 10% of the measured value. NRC staff acknowledge that this 10% uncertainty level may not always be achievable, especially in certain cases with concentrations close to the method detection limit. Therefore, NRC staff should evaluate whether instrument performance and data quality are adequate to produce a reasonable demonstration, given practicalities of the measurements. NRC staff should ensure that licensees use the best estimates of annual average concentrations in demonstrations of compliance. If MDCs are insufficient (i.e., too high) or overall relative uncertainties in measured quantities are too high, and if radon emissions are such that compliance is in question, licensees should evaluate improvements to monitoring techniques that would reduce the uncertainties and the likelihood of measurement results incorrectly indicating noncompliance or compliance. Some detector vendors may make available detector analyses with improved MDCs (by analyzing a larger area of the alpha track material). NRC staff asked one manufacturer and found that the standard sensitivity alpha-track device for the manufacturer has an MDC of 30 pCi-days/L, but a high sensitivity device has a lower MDC of 6 pCi-days/L. Thus, using the higher sensitivity devices or increasing the length of time detectors are deployed can improve (reduce) the MDC and reduce the uncertainty of the measurements.

As also provided by the HPPOS-223 statement, for comparison to a regulatory limit, the uncertainty in the (valid and reasonable) measurements need not be considered in determining compliance. Thus, NRC staff should ensure that, for comparison to a regulatory limit, (i) staff does not require licensees to use the sum of the measured value and its uncertainty; and (ii) licensees do not use the measured value less its uncertainty. Based on this recommendation, NRC staff considers it *inappropriate* to represent background concentration by the average plus some multiple of the standard deviation. Such an approach would be inconsistent with the HPPOS-223 recommendation to compare the measured value (and not the measured value less its uncertainty) to the limit and would also be a non-conservative approach. As such, this approach generally should not be approved by NRC staff. In addition, the standard deviation of the measurements (typically 3-month or 6-month measurements) would represent a combination of measurement uncertainty and temporal variability; the standard deviation is thus not a representation of uncertainty for the annual average concentration.

Another method to reduce measurement uncertainties is to use multiple detectors at each monitoring location. The average of the multiple detector results should have lower uncertainty than the results from single detectors.

In some cases, licensees may evaluate whether statistically significant differences exist between measured radon concentration for multiple locations; in particular, comparing concentrations at background locations to those at other locations (e.g., potential receptor locations) or comparing among multiple background measurement locations. NRC staff should evaluate these statistical comparisons and should verify that licensees have used appropriate statistical tests. Some useful statistical references are Helsel and Hirsch (2002), Gilbert (1987), and NRC (2011). Staff also should consider two references that, while developed for evaluation of site cleanup and ground-water monitoring data, respectively, include methods relevant to evaluations of data for radon in air: NRC (1998), which includes a nonparametric method to demonstrating indistinguishability from background; and EPA (2009), which includes discussions of statistical evaluation methods and the establishment of background. In most cases, the data would be paired data (i.e., receptor location and background location at the same time). For paired data, tests for paired data (or matched-pair tests) should be used. Appropriate tests include the sign test, Wilcoxon signed rank test (not to be confused with the Wilcoxon rank sum test), or paired t-test. Staff should evaluate whether assumptions of the tests (symmetric distribution of differences for the Wilcoxon signed rank test; normal distribution of differences for the paired t-test) have been met. NRC staff may consider other statistical approaches to evaluating indistinguishability on a case-by-case basis.

If licensees conclude that concentrations at potential compliance locations are indistinguishable from background, staff should verify that the monitoring program was sufficient to distinguish differences in radon and radon progeny concentrations that would result in doses above the limit of 100 mrem/yr. For statistical comparisons, staff should consider the complication that concentrations at different locations may rise and fall in unison with time (e.g., seasonal variations). Due to such temporal variability, data for all locations used in the comparisons should represent the same time period. Also, staff may consider a method to adjust for these temporal fluctuations (Lang *et al*. 1987). Staff also should consider whether a sufficient time period of data (and thus a sufficient number of data points) has been collected to make a determination on statistical differences between locations; in some cases, it would be acceptable to have more than one year of data on which to base such statistical comparisons. Licensees may commit to collect data for additional years and continue to perform the statistical tests in future years with the cumulative data from multiple years. For this purpose, the data are not used to determine an annual dose for compliance, so more than one year of data may be acceptable, but NRC staff should consider that compliance with the public dose limit is on an annual basis.

NRC staff should be cognizant of presentations at a workshop NRC staff held April 2, 2014, to discuss the revised draft of this ISG and associated issues, summarized in NRC (2014). As indicated in the NRC staff summary of the workshop (NRC 2014), parts of the workshop included discussions of suggestions for improving measurements of radon in air using alpha-track detectors. In particular, a presentation by a vendor of alpha-track detectors[4] (Salasky 2014) included such suggestions. In addition, a presentation by the National Mining Association (Paulson 2014) provided suggestions, with the presentation describing the suggestions as originating from the detector vendor. Based on the presentations and discussions, NRC staff should evaluate whether licensees using alpha-track detectors to measure environmental radon in air have employed the following to improve quality of measurements, including accuracy, precision, and sensitivity (MDC).

- Modify the assembly of the alpha-track detector using “just in time” assembly, to reduce storage time and the number of background tracks on the detectors (Salasky 2014, Paulson 2014).
- Increase exposure time for the detectors to 6 months (180 days) to increase the time-integrated radon concentration (Salasky 2014, Paulson 2014).
- Consider use of a different alpha-track device with a higher calibration factor (i.e., higher response to a given time-integrated radon concentration (Salasky 2014).
- Institute a quality assurance/quality control program including use of blank detectors and spiked detectors (using a radon chamber) (Paulson 2014).

The staff also notes that in some cases a licensee may have asked the detector vendor to use a background (number of tracks) based on the specific chip lot or batch, rather than overall average, to provide the most accurate background track subtraction and concentration results for measurement of low radon concentrations. In addition, the alpha-track vendor presentation (Salasky 2014) briefly discussed a new alpha-track radon monitoring device that was indicated to have a larger active volume and larger read area which results in lower uncertainty. Licensees may wish to consider using new monitoring devices with improved performance if the devices meet appropriate data quality objectives.

[4] Note: NRC staff does not endorse products from any specific vendor.

4.6 Radon Progeny Measurements

In some cases, it may be appropriate for licensees to measure radon progeny concentrations directly for use in determining compliance. One example is a case in which members of the public are visitors to a controlled or restricted area where the radon progeny concentration in air is high enough that it is practical to measure radon progeny concentrations directly. NRC staff should verify that an appropriate technical basis has been provided for the measurement methods used.

If licensees use this direct measurement method, NRC staff should carefully evaluate details of the implementation. Radon progeny concentrations typically are measured with grab sampling and evaluation by the Kusnetz analysis method, which is a short-term assessment, or similar analysis method (National Council on Radiation Protection and Measurements (NCRP) 1988). Radon progeny concentrations are expected to vary diurnally and over longer time periods. The measurements should be representative of the long-term average equilibrium factor, since the long-term average is what is appropriate for compliance purposes. Thus, if a short-term measurement technique is used, staff should ensure that licensees have made enough short-term measurements, at the appropriate times of day and times of year, to represent the annual average concentration. Licensees should justify that the measurements are representative.

The Kusnetz analysis method and similar methods typically are used in occupational settings in which relatively higher concentrations exist. If these methods are used for environmental measurements, NRC staff should evaluate the sensitivity of the measurements. Staff should verify that licensees have shown the sensitivity and uncertainty of the technique is sufficient and appropriate for the radon progeny concentrations of concern.

If a licensee chooses to measure radon progeny indoors, another issue to consider is the impact of opening doors or windows on the determination of the radon progeny concentrations. This issue may be most important when short-term measurement techniques are used (such as grab sampling). EPA (1992) provides some recommendations on protocols for indoor measurements. It may be difficult to determine the background radon progeny concentration to subtract for determining net concentrations. In some cases, it may be reasonable to disregard and not subtract background and yet still demonstrate compliance. If background is subtracted, NRC staff should evaluate the background measurements considering the potential issues for background and for radon progeny measurements.

4.7 Radon Measurement Locations

NRC staff reviewers should evaluate the licensee's determination of measurement locations. As discussed earlier, licensees should evaluate which members of the public are likely to receive the highest dose from licensed operations. 10 CFR 20.1301(b) specifies that if the licensee allows members of the public have access to controlled areas, the public dose limit continues to apply to those individuals; members of the public in controlled areas, such as vendors or non-licensee workers, should be considered as potential highest exposed individuals. Licensees should establish monitoring locations to support compliance demonstrations for the members of the public potentially receiving the highest dose. If the compliance method of comparing to Appendix B values is used, licensees should establish monitoring locations at the *boundary of the unrestricted area*, consistent with 10 CFR 20.1302(b)(2)(i). If licensees elect to use this method, then NRC staff would expect that such areas be clearly documented and therefore be referenced in their compliance demonstration.

RG 4.14 (NRC 1980) recommends that the radon sampling stations be co-located with the air particulate monitoring stations, and that airborne particulate samplers be placed in the following locations: (1) a least three locations at or near the site boundary; (2) the nearest residence or occupiable structure within 10 kilometers of the site with the highest predicted airborne radionuclide concentration; (3) at least one structure where predicted doses exceed 5 percent of the standards in 40 CFR Part 190; and (4) a location representing background conditions. NRC staff notes that this recommendation of RG 4.14 may not be completely consistent with the 10 CFR Part 20 requirements, as the RG refers to the site boundary, which may differ from the boundary of the unrestricted area and from areas within the controlled areas to which members of the public may be permitted access; however the requirements in the regulation take precedence over the guidance.

NRC staff reviewers should determine if licensees have evaluated which members of the public are likely to be the most highly exposed due to licensed operations. If the licensee allows the public access to controlled areas of the facility, then the licensee also needs to demonstrate that the dose to these members of the public does not exceed the 10 CFR 20.1301 limit or effluent concentration values. Additional monitoring locations inside controlled areas (i.e., in addition to the typical “fenceline” locations) may be appropriate to provide data to determine radon concentrations to which people who access controlled areas may be exposed.

In determining monitoring locations, the licensee is also expected to take both point and diffuse or area sources into account. Diffuse sources include, for example, radon emanating from the wellfields at ISR facilities, or tailings and ore pads and storage areas at conventional or heap-leach facilities. Point sources may include, for example, radon from the ion exchange column captured by an exhaust system and released through a roof stack.

It may be beneficial for licensees to deploy detectors at additional locations to provide more comprehensive data about the variations in radon concentrations around a facility.

NRC staff reviewers should evaluate whether monitoring locations are representative and appropriate. If monitoring is performed at a limited number of boundary or fenceline locations, some of the locations should be chosen in directions of expected highest concentrations from facility releases. These directions can be determined based on meteorological data for the facility. If onsite meteorological data is not available, licensees should justify acceptability of using offsite, nearby data to represent site meteorology.

NRC reviewers should note that there may be difficulties in predicting locations of the expected highest radon concentrations. Many uranium recovery facilities are located in valleys where the air flows important to highest radon concentrations (least dispersion) may be upvalley (upslope) and downvalley (drainage) flows. These upslope and drainage flows are localized flows that set up in valley systems based on gravity (cool air at night is denser and thus drains downvalley while warm air during the daytime is less dense and tends to rise upvalley) (Till and Grogan 2008).

Shearer and Sill (1969) performed radon in air surveys around four uranium mill tailings sites and found that valley flows were important at two of the locations. Others have noted the significance of these valley flows for radon concentrations around tailings or other sources of radon releases. In many cases, the low speed, drainage winds that occur at night under relatively stable atmospheric conditions are the winds that may result in the highest radon concentrations and may contribute the most to annual doses. Thus, effects of topography should be considered when determining likely locations of highest radon concentrations.

It is unclear whether typical meteorological monitoring stations will adequately characterize the low wind speed drainage flows that may be critical for radon concentrations. One issue is that in areas of complicated topography, where these flows are important, it may be difficult to characterize the meteorology with a single monitoring station because air flows will vary across the site. In cases where meteorological data are used to determine monitoring locations, licensees and staff should be aware of these potential difficulties and licensees should demonstrate that the meteorological data is consistent with long-term conditions at the site. In some cases, instead of using meteorology to guide monitoring locations, it may be reasonable, at least initially, to use a larger radon monitoring network (i.e., more monitoring locations) to provide reasonable assurance that the locations of expected highest radon concentrations are monitored. Or, it may be reasonable to model air dispersion using models that account for topography. NRC staff does not have specific recommendations in this regard; this would need to be determined on a case-specific basis.

Another difficulty with locations for radon monitoring is distance from the release points. At some distance from a radon source, the air dispersion will reduce air concentrations of radon such that the concentrations are indistinguishable, statistically, from background or preoperational concentrations. Shearer and Sill (1969) studied radon concentrations around conventional uranium mill tailings sites, in particular making measurements at 25 locations on and around the tailings pile in Grand Junction, CO. Based on the measurements around the Grand Junction tailings pile, their results showed that at a distance of 800 m (0.5 mile) from the pile, some of the prevailing-wind direction locations had average concentrations that were statistically different from other off-pile station averages. However, at a distance of 1600 m (1 mile) (the next-closest monitoring locations) or more from the pile, none of the individual monitoring station averages could be considered statistically different (at 95 percent confidence level, based on standard t-test and analysis of variance techniques) from each other. At the time of the measurements, the tailings at the Grand Junction mill site were uncovered. At most ISR facilities, radon releases are expected to be lower than observed by Shearer and Sill at conventional mills, and the distance to where measured radon concentrations would be indistinguishable from background would be less than 1600 m (1 mile). This study around Grand Junction is just one study, and results could be different at different sites with different measurement methodologies. But it does point out that at some distance away from the source of radon emissions, concentrations in air due to releases from the facility will be indistinguishable from the natural background concentrations. Thus, when feasible, there can be a benefit to performing monitoring close enough to the facility that differences from background are expected to be statistically significant. For some facilities, members of the public may not have access close to the facility for extended periods of time; however, close-in measurements may still be useful in bounding exposures to members of the public (and in assessing worker exposures).

Licensees for which there is substantial variability in background radon concentrations around the facility may wish to consider additional monitoring as follows. Additional monitoring locations could be used close enough to the facility that differences in measured radon concentrations (that may include contributions from the facility) from background concentrations are expected to be significant and measurable. Modelling of the transport of radon in air to receptors and points of compliance could be performed, with additional modelling results corresponding to the close-in monitoring locations. Monitoring results from the close-in monitoring locations could then be used in combination with the modelling results for the demonstration of compliance. The measurements could be used to confirm that the model is reasonable for predicting concentrations around the facility and/or to confirm that the regulatory limits are not exceeded. For such cases, NRC staff should evaluate on a case-by-case basis the modelling and use of measurements to evaluate the modelling performance.

4.8 Annual Average Concentrations Should Be Used for Compliance

The public dose limit of 10 CFR 20.1301 is an *annual* limit. In addition, for using the Appendix B compliance method, 10 CFR 20.1302(b)(2)(i) specifies that *annual average* concentrations do not exceed the values of Part 20, Appendix B. Thus, in general, annual average concentrations should be used in compliance demonstrations, whether using the dose assessment or Appendix B compliance method.

When concentrations are used for purposes other than direct compliance demonstrations (e.g., for comparison of measured to modelled concentrations), other averaging periods may be appropriate, but should be representative for the purpose.

4.9 Radon Progeny Equilibrium Factor

For dose calculations, long-term average concentrations typically are most appropriate. For radon *progeny* in the environment, there are substantial difficulties in making appropriate long-term measurements (Jenkins 2010, George 1996). Passive methods for environmental measurements of radon progeny are not readily available. Based on the substantial variability in radon progeny concentrations (diurnal, longer-term, and other variability), making grab sample measurements with sufficient frequency to estimate long-term averages may be impracticable.

Because of the difficulties in measuring radon progeny in the environment, the more typical approach is to measure radon concentration, determine an equilibrium factor (sometimes called equilibrium fraction), and then calculate the radon progeny concentration (or the equilibrium effective concentration (EEC) of radon). The EEC is the concentration of radon, in equilibrium with the radon progeny, which would have the same potential alpha energy as the actual mixture of progeny. The equilibrium factor is the ratio of the EEC to the radon concentration. Further details about EEC and equilibrium factor are provided in Jenkins (2010), NCRP (1988), and other basic references on radon. If licensees intend to adjust the 10 CFR Part 20 Appendix B value for radon for an equilibrium factor other than 1.0, or intend to perform a dose assessment to demonstrate compliance with the public dose limit, determining the equilibrium factor is important.

If a licensee adjusts the Appendix B, Table 2, value for radon, NRC staff reviewers should ensure that the licensee has requested and obtained *specific* NRC approval through the licensing process. This ISG does *not* provide approval to licensees to adjust the Appendix B value. See also Section 4.11.3 of this ISG.

NRC staff reviewers should evaluate the licensee's approach for determining the equilibrium factor. The reviewer should determine that the licensee has used one of the following approaches and has provided a technical basis for the approach.

4.9.1 Conservative Value

The simplest and most conservative approach to determining the equilibrium factor is to make the assumption that radon progeny are present in 100 percent equilibrium with radon. Thus, an equilibrium factor of 1.0 is acceptable to NRC staff and considered conservative. However, the licensee does not need to assume 100 percent equilibrium. The following sections describe other acceptable approaches. Approaches different from these will be acceptable if the licensee provides an acceptable basis for the approach.

4.9.2 Generally Acceptable Radon Progeny Equilibrium Factors

Another approach to determining the equilibrium factor is to use equilibrium factors that are generally accepted by NRC staff. Equilibrium factors may be needed for indoor and outdoor exposures. Equilibrium factors provided in this section as generally acceptable are intended to be acceptable for use at any site and therefore are intended to be somewhat conservative.

The NCRP updated its report on the radiation exposure of the U.S. population, published as NCRP Report 160 (NCRP 2009). In this report, NCRP calculates average exposure to the U.S. population, based on average radon concentration and average equilibrium factors. The NCRP exposure model separates exposures into indoors at home, indoors away from home, and outdoors. NCRP used the same equilibrium factor for indoors at home and indoors away from home. NCRP summarized data on equilibrium factor from several sources. For the equilibrium factor for indoor exposures, NCRP used a central value of 0.4, and considered the uncertainty range of the central value to be 0.3 to 0.5. (For perspective, NCRP considered the average background radon concentration indoors in homes to be 1.2 pCi/L.) For the equilibrium factor for outdoor exposures, NCRP used a central value of 0.6, considered the typical values to be 0.5 to 0.7, and stated that a wider range of values can be found (0.2 to 1.0). (For perspective, NCRP considered the average background radon concentration outdoors to be 0.4 pCi/L.)

Indoor exposures. For indoor exposures, especially in houses, the equilibrium factor is primarily dependent on conditions of the building because of typical air exchange rates less than 1 hr^{-1} (Nazaroff and Nero 1988). Schiager (1974) states that in determining the indoor radon progeny concentration, the critical factor (in addition to the radon concentration) is assessment of the mean residence time of the radon in the indoor atmosphere. For purposes of assessing indoors exposure to radon progeny, NRC staff should assume that outdoor radon from a facility enters a home with very little progeny present (i.e., it is assumed most of the progeny plate-out on surfaces of the cracks through which the radon enters the home). NRC staff should assume that progeny in-growth indoors is based on the characteristics of the home, especially the air exchange rate (which can be related to mean residence time of air).

For indoor exposures, RG 3.51 provides a generally acceptable equilibrium factor. Appendix C of RG 3.51 provides technical basis information that NRC staff uses for a radon progeny inhalation dose conversion factor. The appendix states that a ratio of 5×10^{-6} WL per pCi/m^3 of radon is established by the assumed indoor air concentration ratios of the individual radon progeny. The relationship between radon concentration, progeny concentration, and equilibrium factor is: progeny concentration (in WL) = radon concentration (in pCi/m^3) × equilibrium factor × (1 WL per 100 pCi/L radon at equilibrium) × (1×10^{-3} m^3/L). Based on this relationship, the value of progeny concentration per radon concentration in the appendix is equivalent to an assumption of an equilibrium factor of 0.5. Thus, for indoor exposures, NRC staff would find acceptable an equilibrium factor of 0.5.

NRC staff notes that from the NCRP 160 assessment (NCRP 2009), the upper value of the uncertainty range on the *average* equilibrium factor for indoors was also 0.5. This supports the use of a value of 0.5 as generally appropriate for most sites.

Outdoor exposures. For outdoor exposures, previous NRC staff guidance does not provide a generally acceptable value for the equilibrium factor. Therefore, as follows, NRC staff considers use of values from NCRP 160 acceptable. NCRP applied the central values to estimate exposures of the entire U.S. population. However, for compliance with the NRC public dose limit, exposures to individuals must be evaluated, so NRC staff considers use of an overall average to be nonconservative for some individuals in the population. Thus, for outdoor exposures, NRC staff would find acceptable use of the upper value of the NCRP's typical range, which is 0.7. Two studies determined equilibrium factors for outdoors (Wasiolek and Schery 1993, Wasiolek and James 1995). In these two studies, equilibrium factors ranged from 0.38–0.95 for individual locations, with overall means of 0.66 and 0.63 for the two studies. NRC staff should recognize that radon released from a uranium recovery facility would not likely achieve such a high equilibrium until it is a long distance from the facility. Thus, this value (i.e., 0.7) may overestimate the equilibrium factor for the radon from the facility at actual receptor or point of compliance locations close to the facility. NRC staff does not presently have a technical basis for endorsing a lower value that could be generally applicable to all conditions. Alternatively, it may be appropriate for licensees to determine a site-specific value as discussed in Section 4.9.3.1 of this ISG.

Combined residential exposures. For combined indoor and outdoor exposure of residents exposed at their residence relatively close to the facility, NRC staff considers an equilibrium factor of 0.5 to be generally acceptable, based on the following. Distributions of exposure time indoors and outdoors are developed in NUREG/CR-5512, Vol. 3 (NRC 1999). At the 90th percentile, times spent indoors, outdoors, and gardening are 266, 58, and 7 days per year, respectively (values do not add up to 365 due in part to an assumption that some time is spent offsite). If these times are used to weight the generally acceptable indoor and outdoor equilibrium factors, the weighted average equilibrium factor is 0.5. NRC staff considers this value generally acceptable to use for typical cases of residential exposure (indoors and outdoors, with majority of time spent indoors) relatively close to the facility. This value should not be used in cases where it is known that outdoor exposure times are significantly more than described above and the travel time is long enough that the outdoor equilibrium factor from progeny in-growth is expected to be significantly greater than 0.5.

4.9.3 Site-specific Radon Progeny Equilibrium Factor Values

A third approach to determining the equilibrium factor is to base it on site-specific conditions. NRC reviewers should ensure that licensees (and applicants) have provided sufficient technical basis for this approach.

4.9.3.1 Outdoor equilibrium factor by travel time. For outdoor exposures, one site-specific approach acceptable to NRC staff would be to determine radon progeny in-growth time or the time that it takes radon to be dispersed to the unrestricted area boundary or the nearest resident (or other receptor) location. Fractional in-growth of progeny can be calculated for this travel time based on standard equations for in-growth of progeny. Two references that provide information on radon progeny in-growth are the EPA CAP88-PC Users Guide (EPA 2007) and a journal article, *Engineers' Guide to the Elementary Behavior of Radon Daughters* (Evans 1969). Evans provides curves of radon progeny in-growth as a function of time. If licensees use this method, NRC staff should evaluate applicability of the method. The method is more easily used for sources in which the radon release is essentially pure radon gas, that is, where the equilibrium factor at time of release is essentially zero. In addition, the basis for the travel time used should be carefully considered. The equilibrium factor is not a linear function of (i.e., not directly proportional to) wind speed. Thus, if a licensee proposes using mean wind speed to calculate travel time and the resultant equilibrium factor, the licensee should provide technical justification that use of the mean wind speed is appropriate. Alternatively, if full meteorological data are available for the site, licensees may use the MILDOS-AREA code for the purpose of calculating the equilibrium factor from in-growth of radon progeny.

This method for determining equilibrium factor may be particularly appropriate for exposures of members of the public allowed access to outdoor controlled areas of the site (e.g., coal-bed methane workers routinely accessing controlled outdoor areas), if these members of the public are likely to receive the highest dose from licensed operations.

4.9.3.2 Indoor equilibrium factor by measurement. For indoors exposures, one site-specific approach would be to measure radon concentrations and radon progeny concentrations indoors at actual receptor locations, and calculate the equilibrium fraction. NRC staff should assume that outdoor radon from a facility enters a home with very little progeny present. NRC staff should assume that progeny in-growth indoors is based on the characteristics of the home, especially the air exchange rate (which can be related to mean residence time of air). Thus, an equilibrium factor determined for a house should be applicable to the indoor radon that is due to facility releases.

NRC staff should note that radon concentrations are usually expressed in pCi/L, while radon progeny concentrations are often expressed in WL. Conversion of units is based on 1 WL being equivalent to 100 pCi/L of radon with the progeny in equilibrium. Thus, if these units are used, the equilibrium factor can be determined as follows:

$$F = \left(\frac{radon\ progeny\ concentration\ (\mathrm{WL})}{radon\ concentration\ (\mathrm{pCi/L})}\right) \times \left(\frac{100\ \mathrm{pCi/L}}{\mathrm{WL}}\right)$$

If licensees use this method, NRC staff should evaluate details of the implementation. Radon and radon progeny typically are measured with different techniques that are not necessarily comparable. Both radon and progeny concentrations are expected to vary diurnally, but the two do not necessarily vary identically in time; therefore, the equilibrium factor is expected to vary in time (diurnally). Radon and progeny concentrations also vary seasonally. Thus, the radon and progeny measurements should be made at the same time and should be integrated over the same time period (e.g., either grab samples used for both measurements or integrated measurements made concurrently in time) so that it is reasonable to calculate an equilibrium factor. The measurements also should be representative of the annual average equilibrium factor, as the annual average is what is appropriate for compliance purposes. If different time periods are used for the radon and progeny measurements, both measurements should be representative of an annual average.

See also Section 4.6 regarding considerations for measurement of radon progeny.

A National Academy of Sciences (NAS) report on the health effects of radon exposure (the “BEIR VI” report, NAS 1999) states that the equilibrium factor ranges from 0.2 to 0.8. NRC staff should note this range of expected values; values determined by licensees for indoor air outside this range would be unexpected and NRC staff should evaluate the methods carefully.

4.9.3.3 Outdoor equilibrium factor by measurement. For outdoor exposures, one site-specific approach would be to measure radon concentrations and radon progeny concentrations outdoors at actual receptor locations, and calculate the equilibrium fraction. This method may be relatively conservative, since the measurements would represent the equilibrium factor for the radon from all sources, not just the facility-related radon. If this method is used, the same considerations of measurements being made at the same time and for the same time periods applicable to measurement of equilibrium factor indoors would also apply to outdoor measurements.

4.9.4 Summary of Acceptable Equilibrium Factor (F) Values and Approaches

The table below summarizes acceptable values of and approaches to measuring the equilibrium factor. If receptors are exposed indoors and outdoors, it would be reasonable to use equilibrium factor values separately for indoor and outdoor exposure time (if appropriate to compliance method) or to use the more conservative of the two equilibrium factor values.

4.10 Compliance with 10 CFR 20.1301 and Assessment of Dose to Members of the Public in a Controlled Area

NRC staff reviewers should determine if licensees have evaluated which member of the public is likely to be the most highly exposed due to licensed operations. As stated in 10 CFR 20.1301(b), if the licensee allows the public access to controlled or restricted areas of the facility, then the licensee also needs to demonstrate that the dose to these members of the public does not exceed the 10 CFR 20.1301 limit. NRC staff notes that some licensees provide onsite residences for workers; while off-duty, these people are considered members of the public. In other cases, members of the public may be in controlled or restricted areas (as visitors or as part of their non-radiological work). The following discusses one approach to assessing dose for members of the public in controlled or restricted areas, but NRC staff should ensure that licensees *also* determine which member of the public is the individual likely to receive the highest dose and demonstrate compliance for that individual (see Section 4.12.1 of this ISG).

One acceptable approach to demonstrating compliance for members of the public accessing controlled areas is described in NUREG/CR-6204, *NRC's Questions and Answers Based on Revised 10 CFR Part 20* (NRC 1994a), in the answer to Question 104. This answer indicates that it would be acceptable to demonstrate compliance with the annual dose limit for members of the public in a controlled area by applying the effluent concentration criteria referred to by 10 CFR 20.1302(b)(2) to the controlled area rather than to the unrestricted area boundary. This would involve comparing concentrations determined (by survey, generally by measurement) for the controlled area where the members of the public are exposed (or at locations that conservatively determine concentrations to which the members of the public would be exposed) to the 10 CFR Part 20, Appendix B, Table 2, value. To the extent that licensees establish controlled areas, this method may be used in such controlled areas.

Alternatively, licensees may perform dose assessments to demonstrate compliance for members of the public in controlled areas.

Acceptable Values of and Approaches to Determining the Equilibrium Factor.			
Type of survey	**Receptor location**	**Equilibrium factor or approach [1, 2]**	**Notes**
Most conservative, always acceptable	indoors or outdoors	1.0	
Generally acceptable	outdoors [3]	0.7	consistent with NCRP 160 approach
	indoors [3]	0.5	based on RG 3.51, consistent with NCRP 160 approach
	residential exposure	0.5	see text for conditions on use
Site-specific	outdoors [3]	in-growth calculations based on travel time	
		measure radon and progeny separately and calculate equilibrium factor	considered unlikely to be used
	indoors [3]	measure radon and progeny separately and calculate equilibrium factor	

1 If a licensee is using an equilibrium factor other than 1 to adjust the 10 CFR 20, Appendix B, Table 2, values for compliance, the licensee must request and obtain specific NRC approval for the adjustment through the licensing process. This ISG does not provide approval to licensees to adjust the Appendix B value. See also Section 4.11.3 of this ISG.

2 Acceptance of dose assessment methodology generally is part of the technical licensing basis. Changes to a licensee's dose methodology, including changes in equilibrium factor, are addressed through the licensing process.

3 If receptors are exposed indoors and outdoors, it is acceptable to use separate equilibrium factor values for indoor and outdoor exposure time, or to use the more conservative equilibrium factor value.

4.11 Compliance with 10 CFR 20.1301/1302 by Comparison to 10 CFR Part 20, Appendix B, Effluent Concentration Values

4.11.1 10 CFR Part 20, Appendix B, Table 2, Value for Radon in Air

Appendix B, Table 2, includes values for radon-222 "with daughters removed" and for radon-222 "with daughters present." The short-lived radon progeny will be the principal contributor to radiation dose in most practical radon exposure situations. NRC staff does not envision cases at uranium recovery facilities where radon progeny (daughters) will have been completely removed from air to which the public is exposed. Appendix 1 of this present guidance provides discussion of the regulatory basis for NRC staff concluding that radon progeny will be present and that uranium recovery facilities are expected to use Appendix B, Table 2, values for radon with daughters present.

NRC staff concludes that the correct Appendix B, Table 2, value for air for uranium recovery facilities is that for radon-222 “with daughters present,” which is 1×10^{-10} μCi/mL, or 0.1 pCi/L.

4.11.2 Measure Concentrations in Effluents at Boundary of Unrestricted Area

For compliance by comparison to the Appendix B, Table 2 values, 10 CFR 20.1302(b)(2)(i) requires the concentrations of radioactive material to be “at the boundary of the unrestricted area.” NRC staff should evaluate whether measured concentrations of radon in air were measured at the boundary of the unrestricted area. In the past, some licensees have measured radon in air concentrations at fenceline or site boundary and these areas may be beyond the boundary of the unrestricted area. The boundary of the unrestricted area generally would be the boundary between the unrestricted area and the restricted or controlled areas (if established) of the site. Thus, in evaluating a licensee’s use of this method, NRC staff should review where the licensee has established restricted areas or controlled areas.

4.11.3 Adjusting Appendix B Effluent Concentration Value for Equilibrium Factor

The regulation in 10 CFR 20.1302(c) allows, with prior approval from the NRC, licensees to adjust the effluent concentration values of 10 CFR Part 20, Appendix B, Table 2, to take into account actual physical and chemical characteristics of the effluents, including radioactive decay equilibrium. The SOC to the 1991 Part 20 final rule (56 FR 23360, 23375; May 21, 1991) specifically discusses making such adjustments for the actual degree of equilibrium in the environment. This adjustment allows consideration of radon progeny equilibrium factor values other than 1.0 (100 percent equilibrium). An equilibrium factor less than 1 would result in an adjusted value greater than that given in Appendix B, Table 2, for radon with daughters present.

As noted, the adjustment of Appendix B values requires prior NRC approval. This ISG does *not* provide approval to licensees to adjust the Appendix B value; licensees wanting to make an adjustment must request and obtain specific NRC approval through the licensing process.

For licensee requests for approval to adjust the Appendix B value, NRC staff should evaluate the requested adjustment following the guidance on equilibrium factor above in Section 4.5. In reviewing requests, NRC staff should note that 10 CFR 20.1302(c) allows only for adjustment based on physical or chemical properties of the effluents. Thus, if licensees demonstrate compliance by comparing concentrations to the 10 CFR Part 20, Appendix B, Table 2, values, licensees may not use an occupancy factor in the adjustment of the Appendix B value (that is occupancy cannot be accounted for with this compliance method). An adjusted effluent concentration value would be calculated using the equilibrium factor, *F*, as follows:

$$Adjusted\ Effluent\ Concentration\ Value = \frac{(Effluent\ Concentration\ Value)}{F}$$

NRC staff recognizes that in the above equation for adjusting the Appendix B value, it is assumed that all the dose is contributed by the radon progeny, i.e., the radon gas contributes nothing to the overall dose. For values of equilibrium factor greater than or equal to 0.1, this simplified model (equation) would ignore up to about ten percent of the total dose; however, NRC staff considers this acceptable given the inherent uncertainty in the assessment. Thus, NRC staff considers this simplified equation acceptable when the equilibrium factor is within the range 0.1–1.0. If licensees propose adjusting the Appendix B value using an equilibrium factor of less than 0.1, NRC staff should ensure that the licensee has either justified the appropriateness of the simplified equation, if it is used, or has used an adjustment that explicitly accounts for the dose from radon gas and radon progeny. See also the related discussion in Section 4.12.2 of this ISG.

4.12 Compliance with 20.1301/1302 by Performing Dose Assessment

NRC staff reviewers should be aware that acceptance of dose assessment methodology is part of the technical licensing basis. Thus, changes to a licensee's dose methodology are addressed through licensing actions. NRC staff should evaluate a licensee's or applicant's dose assessment methodology considering the following.

4.12.1 Determination of Most Highly Exposed Member of the Public

If a dose assessment is performed to demonstrate compliance, 10 CFR 20.1302(b)(1) requires that the dose to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit. Thus an important part of demonstrating compliance with a dose assessment is determining what individual is likely to receive the highest dose. NRC staff reviewers should determine that a licensee evaluates which member of the public is likely to be the most highly exposed due to licensed operations. Such an evaluation may include some preliminary or screening calculations of different potential individuals and exposure scenarios to support the conclusion determination. If the licensee allows the public access to controlled areas of the facility, then the licensee also needs to demonstrate that the dose to these members of the public does not exceed the 10 CFR 20.1301 limit. NRC staff note that some licensees provide onsite residences for workers; while off-duty, these workers are considered members of the public. NRC staff should review the licensee's evaluation of the most highly exposed individual and should ensure the evaluation has considered the specific potential exposure scenarios at the licensed facility.

4.12.2 Simplified Model for Calculating Dose from Radon and Radon Progeny

The licensee may comply with 10 CFR 20.1301 by demonstrating that the dose (TEDE) to the individual likely to receive the highest dose from the licensed operation does not exceed 100 mrem/yr (1 mSv/yr). NRC staff reviewers should ensure that the licensee has provided the justification for assumptions about the radon and radon progeny equilibrium, the dose conversion factor, and other parameters used to make the dose estimate.

Generally, licensees' dose assessments should be straightforward, and could follow the simple equation:

$$D = DCF \sum_i C_i F_i T_i \qquad \text{(Equation 1)}$$

where:

D = annual dose (CEDE or TEDE) (mrem/yr) due to radon and radon progeny only;

DCF = dose conversion factor for Rn-222 in equilibrium (i.e., 100 percent equilibrium) with the Rn-222 progeny (mrem/yr per pCi Rn/L);

C_i = annual average net (above background) concentration of radon in air (pCi/L) at the receptor location *i*;

F_i = radon progeny equilibrium factor (fraction) for receptor location *i*; and

T_i = occupancy time factor (fraction of a year) for receptor location *i*.

Here, the receptor locations *i* represent the different locations at which an individual is exposed. For example, if a person is exposed at their home indoors and outdoors, *i* would take two values to represent the indoor portion of exposure and the outdoor portion. If a person is exposed only outdoors, *i* would only take a single value, to represent that outdoor exposure.

Surveys of radon concentrations in air should be performed as described in Sections 4.1–4.4 above to determine the annual average radon concentration. Determinations of the radon progeny equilibrium factor should be performed following Section 4.9 above. The occupancy factor and dose conversion factor are discussed in the following sections.

NRC staff recognizes that in the simplified model described by equation 1, it is assumed that all the dose is contributed by the radon progeny, i.e., the radon gas contributes nothing to the overall dose. For values of equilibrium factor greater than or equal to 0.1, this simplified model (equation) would ignore up to about ten percent of the total dose; however, NRC staff considers this acceptable given the inherent uncertainty in the assessment. Thus, NRC staff considers this simplified model acceptable when the equilibrium factor is within the range 0.1–1.0. If a licensee performs a dose assessment using an equilibrium factor of less than 0.1, NRC staff should ensure that the licensee has either justified the appropriateness of the simplified model, if it is used, or has used a model that explicitly accounts for the dose from radon gas and radon progeny.

4.12.3 Receptor Locations and Occupancy Factor

For nearest resident receptors (and other resident receptors), exposure may occur while indoors at home and while outdoors around the home. The dose assessment should either assess exposures both indoors and outdoors or should make conservative assumptions for parameter values (including equilibrium factor and occupancy factor) to address exposures indoors and outdoors. NRC staff should ensure that simplifying assumptions are either realistic or conservative.

Use of an occupancy factor of 1 is considered a screening approach because it is conservative and bounding on realistic occupancy. NRC guidance in RG 3.51 (NRC 1982a) states that for inhalation doses, indoor occupancy of 100 percent is assumed. NRC guidance in Regulatory Guide 1.21 (NRC 2009) recommends that occupancy factors should be assumed to be 100 percent unless site-specific information indicates otherwise. Thus, use of an occupancy factor of 1 is acceptable to NRC staff.

NRC staff reviewers should note that occupancy for almost all specific individuals would be less than 100 percent and licensees do not have to make conservative assumptions about occupancy factors. If licensees use more realistic occupancy factors, NRC staff reviewers should evaluate the justification carefully. The public dose limit of 10 CFR 20.1301 applies to individual members of the public. For demonstrations of compliance with dose assessments, § 20.1302(b)(1) describes that the dose is that “to the individual likely to receive the highest dose from the licensed operation.” Thus, occupancy factors must address occupancy of the actual individuals. It would be inappropriate to apply occupancy factors that were developed to apply to a statistical representation of a group (for example, an *average member* of a critical group), as such a value may be nonconservative for certain individuals around the facility. One acceptable method that may be used to determine occupancy factors is to interview the potentially exposed people. Based on results of the interview, individual occupancy factors can be created based on each person's lifestyle and habits.

In cases where licensees allow members of the public access to controlled areas, the access is usually for limited time (e.g., vendors visiting a site might typically only be in a controlled area a limited number of hours per month). In such cases, it is acceptable to NRC staff for licensees to determine an appropriate occupancy factor, *T*, that is less than 1, for the members of the public; however, the determination should be based on a bounding estimate or on a realistic estimate of occupancy times.

4.12.4 Dose Conversion Factor for Radon at Equilibrium with Progeny

A dose conversion factor based on the effluent concentration value in 10 CFR Part 20, Appendix B, Table 2, for radon-222 with daughters present, and the associated annual dose for continuous exposure is acceptable to NRC staff. NRC staff has determined an acceptable dose conversion factor as follows.

NRC staff considered the annual dose associated with the effluent concentration values. The text pertaining to Table 2 in Appendix B to 10 CFR Part 20, states that the "concentration values given in columns 1 and 2 of table 2 are equivalent to the radionuclide concentrations which, if inhaled or ingested continuously over the course of a year, would produce a total effective dose equivalent of 0.05 rem (50 millirem or 0.5 millisieverts)." In addition, the SOC for the 1991 Part 20 final rule (56 FR at 23387) includes a response to a comment that the limits for occupational and non-occupational exposure to radon-222 and its particulate daughters (progeny) did not appear consistent with other radionuclides in terms of risk. The NRC response stated, in part, that "the concentration limit for members of the general public … like the other airborne concentration limits, represents an effective dose of 0.05 rem per year." NRC staff considers the "concentration limit for members of the general public" to mean the effluent concentration value from 10 CFR Part 20, Appendix B, Table 2.

The Appendix B, Table 2, value for radon with daughters (progeny) present in air is based on the radon progeny being present at 100 percent equilibrium. The Appendix B value is 1×10^{-10} µCi/mL, which equals 0.1 pCi/L. The annual dose is 50 mrem/yr (0.5 mSv/yr). Therefore, the dose conversion factor for radon-222 with progeny at 100 percent equilibrium is determined as 50 mrem/yr (0.5 mSv/yr) divided by 0.1 pCi/L, or 500 mrem/yr (5 mSv/yr) per pCi Rn/L at 100 percent equilibrium. This value is acceptable to NRC staff.

As stated above, NRC staff recognizes that in the simplified model described by equation 1, it is assumed that essentially all the dose is contributed by the radon progeny, i.e., the radon gas contributes nothing to the overall dose. The error in making this simplification is greatest at low values of the equilibrium factor. Based on a comparison of the 10 CFR Part 20, Appendix B, Table 2 values for radon with daughters present and radon with daughters removed, at 100 percent equilibrium the relative dose contribution of radon gas is about 1 percent of the dose contribution of radon progeny. Thus, at an equilibrium factor of 0.1, the error in ignoring the radon gas contribution is about ten percent. Given the overall uncertainty in the dose conversion factor, including the uncertainty due to rounding of values calculated in Appendix B, Table 2, this amount or error is acceptable to NRC staff given the inherent uncertainty in the assessment. Thus, the simplified approach of equation 1 is acceptable for equilibrium factor in the range 0.1–1.0. However, if NRC staff reviewers encounter cases where the equilibrium factor is less than 0.1, the simplified approach is not applicable and NRC staff should conduct a case-specific analysis.

If licensees propose use of a dose conversion factor different from that described above, NRC staff should evaluate the proposed dose conversion factor on a case-by-case basis.

4.13 Compliance when Radon Progeny Are Measured

The majority of the guidance provided in this ISG assumes that 10 CFR 20.1301/1302 compliance demonstrations will be based on measured concentrations of radon. The method of demonstrating compliance by comparing to 10 CFR Part 20, Appendix B, Table 2, values is explicitly based on surveys of radon concentrations. However, there are cases where it may be appropriate for licensees to base compliance demonstrations on measurements of radon *progeny*, rather than radon. When radon progeny concentrations are measured directly, NRC staff prefers that licensees use a dose assessment to demonstrate compliance, for transparency in the demonstration. A dose assessment demonstration based on radon progeny would differ somewhat from a demonstration based on radon measurements, but the demonstration can be similar. NRC staff should consider the following in reviewing cases where a licensee bases compliance on radon progeny measurements.

- If measured radon progeny concentrations are in units of WL, a dose conversion factor for radon progeny can be determined using the conversion of 100 pCi/L radon (at equilibrium) per WL.
- The adjusted DCF is determined to be: DCF = (500 mrem/yr per pCi/L)×(100 pCi/L per WL) = 5×10^4 mrem/yr per WL.
- In compliance demonstrations using equation 1 for the dose assessment, the equilibrium factor is removed from the equation, as equilibrium is already accounted for by measuring progeny directly.

In using this method and the adjustments above, there is an assumption that essentially all of the dose is due to the radon progeny so it is reasonable to assume the radon gas contributes nothing to the overall dose. For cases when the equilibrium factor is expected to be in the range of 0.1–1.0, NRC staff considers this assumption reasonable and acceptable (see Section 4.12.2 of this ISG). NRC staff reviewers should evaluate the specific case to determine if the expected equilibrium factor is within this range (but the value of the equilibrium factor does not need to be known exactly).The following example illustrates these differences for compliance based on radon progeny measurements:

> **Example:** A licensee has a vendor that visits the site on a periodic basis and spends time in the controlled area. The licensee measures the radon progeny concentration in the area in which the vendor works, with representative or conservative measurements. The licensee has determined an average gross radon progeny concentration of 0.018 WL. Note that the licensee does not subtract background radon progeny concentrations. In order to perform a dose assessment, the licensee has recorded the occupancy times of the vendor and has determined the vendor spends 400 hours per year on site. The occupancy factor is thus (400 hr/yr)/(8766 hr/yr) = 0.046. In using equation 1, the equilibrium factor is not used, so the licensee determines:
>
> dose = (radon progeny concentration in WL) × (DCF for progeny) × (occupancy factor)
> = (0.018 WL) × (5×10^4 mrem/yr per WL) × (0.046) = 41 mrem/yr.

If this dose, combined with the dose from direct exposures and dose from any particulate releases, is no greater than 100 mrem/yr, then the licensee has demonstrated compliance with 10 CFR 20.1301/1302.

5 SUMMARY OF KEY POINTS FOR TECHNICAL REVIEWS

This ISG addresses doses to members of the public from radon and radon progeny from uranium recovery facilities including: (1) surveys of environmental and effluent radon and radon progeny in air; and (2) radon-related aspects of demonstrations of compliance with the public dose limit of 10 CFR 20.1301. This ISG provides guidance on a number of technical issues. The following summarizes some key points that NRC staff reviewers should consider the following.

- When dose assessments are performed for compliance with 10 CFR 20.1301/1302, licensees must address all significant exposure pathways and all radionuclides (not just radon and radon progeny). [see Section 3 for more information]
- When the Appendix B method is used for compliance with 10 CFR 20.1301/1302, licensees must address all radionuclides in effluents, including radon and radon progeny and others as applicable. [3]
- When dose assessments are performed to assess exposure of nearby residents to radon and its progeny, the assessment should address the indoor occupancy. If an equilibrium factor other than 1 is used, it must address the indoor equilibrium for the indoor occupancy time. [4, 4.2.1, 4.9]
- One acceptable survey method is to perform environmental measurements of radon in outdoor air at appropriate locations and apply an equilibrium factor to determine radon progeny concentrations. There are options to survey approaches. [4.2]
- Licensees may use calculations as part of the radon and radon progeny surveys, but NRC staff practice is that licensees generally would perform environmental monitoring to compare measured concentrations of radon or radon progeny to modelled concentrations. [4.2.2, 4.2.3]
- Background concentrations of radon may be subtracted from gross concentrations. However, the determination of background may be complicated. [4.3]
- Licensees can reduce the uncertainty in measured radon concentrations by using detectors with better sensitivity, using multiple detectors at each location, and improving their measurement quality assurance programs. [4.5]
- In determining monitoring locations, RG 4.14 provides some guidance. NRC staff should be aware of additional considerations for monitoring locations. [4.7]
- For determining an equilibrium factor, generally acceptable values are provided [4.9.2].
- Compliance with 10 CFR 20.1301/1302 must address members of the public who are likely to receive the highest dose, which may include an individual member of the public exposed onsite. [4.10]
- Compliance with 10 CFR 20.1301/1302 must account for radon *progeny*. [4.11.1 and Appendix 1]
- When radon in air concentrations are compared to values from 10 CFR Part 20, Appendix B, Table 2 (the “Appendix B method”), for compliance with 10 CFR 20.1301/1302, the Table 2

value for radon with daughters present must be used. The Appendix B, Table 2, value may be adjusted to account for the progeny equilibrium factor, with specific NRC approval. [4.11.1 and 4.11.3]

- When the Appendix B method is used for compliance with 10 CFR 20.1301/1302, the concentrations must be for effluents measured at the boundary of the unrestricted area. These locations may differ from locations suggested in RG 4.14. [4.11.2]
- For dose assessments, an acceptable dose conversion factor for radon with progeny is 500 mrem/yr per pCi/L at 100 percent equilibrium (of radon progeny). [4.12.2]

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APPENDIX 1: REGULATORY STATEMENTS OF CONSIDERATION AND NRC STAFF CONCLUSIONS REGARDING 10 CFR PART 20 AND RADON PROGENY

This Appendix provides relevant background and excerpts from statements of consideration (SOC) associated with 10 CFR Part 20 regarding radon progeny. Currently, 10 CFR Part 20, Appendix B includes Table 2 values for radon-222 “with daughters removed” and for radon-222 “with daughters present.”

In 1974, the U.S. Atomic Energy Commission (AEC) proposed a revision to the occupational limit for exposure to radon-222 and its progeny (39 FR 22428; June 24, 1974). The change was proposed to conform the AEC regulations to the recommendations of the U.S. Environmental Protection Agency. In part, the AEC stated:

> The limit for radon would be replaced by a limit on radon daughters because the daughters are the major health hazard.

The AEC also stated that the revised limit would be consistent with recommendations of the International Commission on Radiological Protection, in its Publication 2, and the National Council on Radiation Protection and Measurements. Both organizations had recommended the same Rn-222 concentration where the daughters “are assumed present to the extent they occur in unfiltered air.” The NRC finalized the rule in 1975 (40 FR 50704; October 31, 1975) and the final limit, given in Table I of Appendix B to 10 CFR Part 20, was expressed as a concentration of Rn-222 (3×10^{-8} µCi/mL), where it was assumed the radon progeny were also present. The limit for public exposure, in Table II of Appendix B, while not changed, was expressed in the same terms. For both the occupational and public limits, the values could be replaced by concentrations of radon daughters expressed in working levels (one-third and one-thirtieth for the occupational and public limits, respectively). Thus, at that time, NRC regulations recognized that the major health hazard was the radon progeny and the limits were based on radon progeny being present with the Rn-222.

The NRC did not change the limits for occupational or public exposure to radon in air until the major revision of 10 CFR Part 20 in 1991. The SOC for the 1991 final rule (56 FR 23360, 23374; May 21, 1991) mentions this issue in context with uranium mills. In discussing the public dose limit and compliance with 40 CFR Part 190, the SOC states:

> For uranium mills it will be necessary to show that the dose from radon <u>and its daughters</u>, when added to the dose calculated for 40 CFR Part 190 compliance, does not exceed 0.1 rem. [Emphasis added.]

The SOC also indicates that uranium mills and ISR facilities may have difficulty in determining compliance with the values in Table 2 of Appendix B to 10 CFR Part 20 for Rn-222. In describing how licensees could adjust values in Appendix B, the SOC state (56 FR at 23375):

> For example, uranium mill licensees could, under this provision, adjust the table 2 value for radon (<u>with daughters</u>) to take into account the actual degree of equilibrium present in the environment. [Emphasis added.]

Thus, the 1991 SOC indicates that NRC expected that uranium recovery facilities would use the value for radon-222 with daughters (progeny) present to determine compliance.

NRC staff concludes that the short-lived Rn-222 progeny will be the principal contributor to radiation dose in most practical radon exposure situations. NRC staff does not envision cases at uranium recovery facilities where progeny (daughters) will have been completely removed from air to which the public is exposed. Based on the discussion above, NRC expects that radon progeny will be present with Rn-222 and that uranium recovery licensees would use the 10 CFR Part 20, Appendix B, Table 2, value for Rn-222 with daughters present. Therefore, NRC staff concludes that the appropriate value from 10 CFR Part 20, Appendix B, Table 2, for uranium recovery facility use, is the value for Rn-222 “with daughters present.” NRC staff also concludes that if a licensee performs a dose assessment to show compliance with 10 CFR 20.1301, the dose assessment must address the dose from radon progeny.

APPENDIX 2: ICRP PUBLICATION 115 AND DOSE CONVERSION FACTOR FOR RADON AND RADON PROGENY

NRC staff should be aware that ICRP Publication 115 (ICRP 2010) was recently issued. This ICRP publication is an update to ICRP Publication 65 (1993). The publication summarizes information available on the epidemiology of the risks of lung cancer associated with exposure to radon and radon progeny in residences and in underground mines; assessment of the detriment from exposure to radon and radon progeny; and conclusions. In part, Publication 115 provides indications of an updated dose conversion factor for radon and its progeny based on more recent studies than evaluated in Publication 65. Publication 115 provides values of effective dose from inhalation of radon progeny derived from the ICRP Human Respiratory Tract model. The publication states: "[f]or typical aerosol conditions in homes and mines, the effective dose is about 13 mSv per [Working Level Month (WLM)]..." In the units used in the present ISG, this is equivalent to a dose conversion factor of about 670 mrem/yr per pCi/L for Rn-222 at 100 percent equilibrium. This value is somewhat higher than the value NRC staff uses based on the present 10 CFR Part 20 (see Section 4.12.2).

In the past, and in the current 10 CFR Part 20, limitations on exposure to radon and radon progeny (as in the Appendix B values) have been based on an exposure determined to represent an acceptable risk (i.e., the occupational inhalation Annual Limit on Intake is 4 WLM), not on determinations of acceptable dose as is done for all other radionuclides. The ICRP will publish revised dose coefficients for inhalation and ingestion of radionuclides based on the recommendations in Publication 103. In its "Statement on Radon" in Publication 115, ICRP stated that ICRP proposes this same approach now be applied to radon and radon progeny (ICRP 2010). At the time this ISG was finalized, ICRP had not yet published its detailed tables of dose conversion factors.

At the time this ISG was finalized, NRC staff had discontinued work on updating 10 CFR Part 20 that had been initiated to address the newest ICRP Publication 103 recommendations (see 81 FR 95410, December 28, 2016). If future rulemaking changes the 10 CFR Part 20, Appendix B, Table 2, effluent concentration values for radon-222, NRC staff should evaluate this ISG to determine if associated changes are needed.