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BIOASSAY AT URANIUM MILLS

A. INTRODUCTION

Purpose

This guide describes a method that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for bioassay programs at uranium mills[1] during uranium recovery operations[2] and applicable portions of uranium conversion facilities[3] where there is a possibility of exposure to the dust of uranium compounds. This guide does not address measurement techniques and procedures.

Applicable Rules and Regulations

- Title 10 of the *Code of Federal Regulations* (10 CFR 20.1204(a), "Determination of internal exposure," (Ref. 1) states that each licensee shall, when required under 10 CFR 20.1502, "Conditions Requiring Individual Monitoring of External and Internal Occupational Dose," take suitable and timely measurements of: (1) concentrations of radioactive materials in air in work areas; or (2) quantities of radionuclides in the body; or (3) quantities of radionuclides excreted from the body; or (4) combinations of these measurements.

- Regulations in 10 CFR 20.1201(e), "Occupational dose limits for adults," require licensees to limit the occupational intake by an individual of soluble uranium to 10 milligrams (mg) per week in consideration of the chemical toxicity.

- Regulations in 10 CFR 20.1703, "Use of individual respiratory protection equipment," require bioassay of workers who use respiratory protection equipment to evaluate actual intake which is assumed to be ambient concentration of radioactive material in air without taking credit for the protection provided by the respirators.

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1 "Uranium milling" means any activity that will result in the production of byproduct material as defined in 10 CFR Part 40.

2 "Uranium recovery" focuses on extracting natural uranium ore from earth and concentrating (or milling) that ore.

3 "Uranium conversion" is the chemical conversion of "yellowcake" (a solid form of mixed uranium oxide) which is produced from uranium ore during uranium recovery (using extraction methods such as conventional mining or in situ recovery) to uranium hexafluoride, which is the chemical form of uranium used in preparation for fabricating fuel for nuclear power plants.

Written suggestions regarding this guide or development of new guides may be submitted through the NRC's public Web site under the Regulatory Guides document collection of the NRC Library at http://www.nrc.gov/reading-rm/doc-collections/reg-guides/contactus.html.

Electronic copies of this regulatory guide, previous versions of this guide, and other recently issued guides are available through the NRC's public Web site under the Regulatory Guides document collection of the NRC Library at http://www.nrc.gov/reading-rm/doc-collections/. The regulatory guide is also available through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html, under ADAMS Accession No. ML13350A638. The regulatory analysis may be found in ADAMS under Accession No. ML110960341 and the staff responses to the public comments on DG-8051 may be found under ADAMS Accession No. ML13350A639.

Related Rules and Regulations

- Regulations in 10 CFR 20.2202, "Notification of incidents," require each licensee to notify the NRC, either immediately or within 24 hours, of any event involving byproduct, source, or special nuclear material possessed by the licensee that may have caused, or threatens to cause, an individual to receive a dose exceeding the limits of this section of the NRC regulations.

- Regulations in 10 CFR 20.2203, "Reports of exposure, radiation levels, and concentrations of radioactive material exceeding the constraints or limits," require a report to be sent to the NRC describing the reportable event.

Related Guidance

- Regulatory Guide 8.9, "Interpretation of Bioassay Measurements," (Ref. 2), provides practical and consistent methods acceptable to the NRC staff for estimating intake of radionuclides using bioassay measurements.

- Regulatory Guide 8.25, "Air Sampling in the Workplace," (Ref. 3), provides guidance on air sampling in restricted areas of the workplace.

- NUREG-0874, "Internal Dosimetry Model for Applications to Bioassay at Uranium Mills," (Ref. 4), provides recommendations in the Table A-1 and Table A-2 regarding the frequency of bioasay, types of bioassay, and recommended corrective licensee actions that licensees may follow.

- The National Council on Radiological Protection and Measurements (NCRP) Report 161, "Management of Persons Contaminated with Radionuclides: Handbook," (Ref. 5), provides guidance for emergency treatment if a severe intake of uranium substances was to occur.

Purpose of Regulatory Guides

The NRC issues regulatory guides to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the NRC's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required.

Paperwork Reduction Act

This regulatory guide discusses information collection requirements covered by 10 CFR Part 20, "Standards for Protection against Radiation," that the Office of Management and Budget (OMB) approved under OMB control number 3150-0014. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number.

B. DISCUSSION

Reason for Revision

This guide was revised to achieve better alignment with: (1) 10 CFR Part 20; (2) the internal dose assessment recommended methods by the International Commission on Radiological Protection (ICRP) Publication 30, "Limits for Intakes of Radionuclides by Workers," (Ref. 6); and (3) the recommended bioassay interpretation method by ICRP Publication 54, "Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation" (Ref. 7).

The guide provides: (1) consensus standard of the American National Standards Institute/Health Physics Society (ANSI/HPS) N13.30-2011, "Performance Criteria for Radiobioassay" (Ref. 8) applicable for uranium mills (this updated version of the standard was not available during the 1988 revision of Regulatory Guide 8.22) and (2) Table 1, "Inhalation Class for Soluble Uranium Compounds," that is based on the 10 CFR Part 20 recommended inhalation class solubility values and associated recommended routine bioassay frequencies considered by staff.

Background

There are two important areas in uranium mill operations where workers could be exposed to uranium. Uranium is radiologically and chemically toxic. Bioassay may be needed due to the primary risks associated with the radiological and chemical exposures, as follows:

a. **Ore-dust areas**: These are the areas beginning with the transfer of ore from the ore pad to the crusher through the final thickening stage. Dust created by uranium extraction and milling activities, or blown by the wind from ore stockpiles, is a potential source of inhalation and contamination.

b. **Yellowcake areas**: These are the areas that contain uranium extracted from the ore in a solution form from the ion exchange or solvent extraction stage through the final packaging into 55-gallon drums to be transported to conversion facilities and become fuel for nuclear power plants.

This regulatory guide describes approaches that uranium mill licensees may use to comply with the bioassay requirements in 10 CFR Part 20; however, practices, methods, or approaches different from those described in this document may be acceptable if they provide a basis for concluding that the licensee operations are in compliance with NRC regulations. In addition, licensees could use the methods described in the U.S. Department of Energy (DOE) Standard, DOE-STD-1136-2009, "Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities" (Ref. 9). Additional information regarding the human respiratory and metabolic models for uranium may be found in ICRP Publications 66, 68, and 71 (Ref. 10-12) and information from chemical standpoint on the latest uranium solubility classifications may be found in the British National Radiological Protection Board (NRPB) Publication W-22 (Ref. 13).

Soluble aerosols[4] (e.g., ammonium diuranate $(NH_4)_2U_2O_7$), uranyl peroxides ($UO_4\ nH_2O$), and uranium trioxide) could generate from the hearths or dryer maintenance; a routine bioassay for drying operators should be performed. The suggested inhalation class based on 10 CFR Part 20 for uranium compounds is tabulated in Table 1. The best time for urine collection is 36-hours post an intake. The

[4] ICRP Publication 30 classifies inhaled material as Class D, W, or Y (days, weeks, or years) depending on their retention time in the pulmonary region. In ICRP 30, the pulmonary half-times actually used for calculating the annual limits of intake are 0.5 days, 50 days, and 500 days for Class D, W, and Y material, respectively,.

delay is necessary to build up uranium content in the kidney; otherwise the body elimination renders them undetectable if it is waited too long. In general, the recommend minimum routine bioassay frequencies are provided in Table 1 for workers involved with operations of Classes D, W, and Y uranium chemicals.

Table 1. Inhalation Class for Soluble Uranium Compounds*

Chemical Form	Inhalation Class	Recommended Routine Bioassay Frequency
UF_6, UO_2F_2, and $UO_2(NO_3)_2$	D (F)	Weekly†
UO_3, UF_4, and UCl_4	W (M)	Weekly†
UO_2 and U_3O_8	Y (S)	Monthly

* Information in this table for inhalation class is taken from Appendix B, 10 CFR Part 20. Both D/W/Y and the equivalent, F/M/S in brackets, refer to an inhalation class as stated in ICRP Publication-30 and Publication-60.

† The NRC considers routine bioassay frequencies that were aligned with the weekly shift schedules. ††

Harmonization with International Standards

The NRC has a goal of harmonizing its guidance with international standards, to the extent practical. The ICRP, NRPB, and the International Atomic Energy Agency (IAEA) have issued a significant number of standards, guidance and technical documents, and recommendations addressing good practices in most aspects of radiation protection. The guidance of this regulatory guide is generally consistent with that provide in these documents. These documents include:

- ICRP Publication 30, "Limits for Intakes of Radionuclides by Workers"
- ICRP Publication 54, "Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation"
- ICRP Publication 60, "Recommendations of the International Commission on Radiological Protection" (Ref. 14)
- ICRP Publication 66, "Human Respiratory Tract Model for Radiological Protection"
- ICRP Publication 68, "Dose Coefficients for Intakes of Radionuclides by Workers"
- ICRP Publication 71, "Age-dependent Doses to Members of the Public from Intake of Radionuclides—Part 4 Inhalation Dose Coefficients"
- NRPB-W22, "Industrial Uranium Compounds: Exposure Limits, Assessment of Intake and Toxicity after Inhalation"
- IAEA Safety Guide RS-G-1.2, "Assessment of Occupational Exposure Due to Intake of Radionuclides" (Ref. 15)

The NRC encourages licensees to consult these international documents and implement good practices that are consistent with NRC regulations. It should be noted that some of the recommendations issued by these international organizations do not correspond to the requirements specified in the NRC's regulations. In such cases, the NRC's requirements take precedence.

Documents Discussed in Staff Regulatory Guidance

Although this regulatory guide uses information, in part, from one or more reports developed by external organizations and other third party guidance documents, the regulatory guide does not endorse these references other than as specified in this regulatory guide. These reports and third party guidance documents may contain references to other reports or third party guidance documents ("secondary references"). If a secondary reference has itself been incorporated by reference into NRC regulations as a requirement, then licensees and applicants must comply with that requirement in the regulation. If the secondary reference has been endorsed in a regulatory guide as an acceptable approach for meeting an NRC requirement, then the reference constitutes a method acceptable to the NRC staff for meeting that regulatory requirement as described in the specific regulatory guide. If the secondary reference has neither been incorporated by reference into NRC regulations nor endorsed in a regulatory guide, then the secondary reference is neither a legally-binding requirement nor a previously approved acceptable approach for meeting an NRC requirement. However, licensees and applicants may consider and use the information in the secondary reference, if appropriately justified and consistent with applicable NRC requirements in 10 CFR Part 20.

C. STAFF REGULATORY GUIDANCE

1. Participation

Individuals should participate in the bioassay programs based on the criteria described below:

a. individuals who could receive dose levels in accordance with 10 CFR 20.1502(a), or 20.1502(b)

b. individuals who work in uranium mills or who are close enough to the process that exposure and intake is possible (e.g., within a few meters and in the same room as the worker handling the radioactive material)

Bioassay program determinations regarding participation and frequency should be based on estimates of the type and quantity of intakes that may occur based on the procedures that are expected to take place at the licensee's facility during the monitoring year. The program is confirmatory in that low or zero results may indicate that the measures in the workplace to control uranium materials are effective and that no unexpected intakes would occur. Based on operational experience, licensees may be able to justify adjustments in their bioassay program, such as a reduction in bioassay routine monitoring frequency, the inclusion of fewer workers in the bioassay program, or licensees may seek an exemption (see 10 CFR Part 20.2301, "Applications for Exemptions").

2. Types of Bioassay Measurement that May Be Performed

The NRC staff considers either indirect bioassay (urinalysis) or direct bioassay (lung/thorax count) for estimation of intake to be acceptable methods for providing bioassay measurements. Licensees may perform both direct and indirect bioassay measurements to assess an intake, but it is not required.

a. Indirect Bioassay (in vitro) – Urinalysis

Urinalysis is recommended to be performed to monitor exposures to all soluble uranium from ore dust and from yellowcake operations.

b. Direct Bioassay (in vivo) – Lung/thorax [5]

Direct lung/thorax measurements is recommended to be performed to detect the presence of (1) the more insoluble (i.e., Class Y) yellowcake component, and (2) uranium in ore dust when air-sampling results indicate an exposure exceeding a concentration of 1×10^{-10} μCi/mL (3.7 μBq/mL).

3. Conditions under Which Bioassay should be Performed

a. Baseline Bioassay (pre-employment or preoperational): Bioassay[6] should be obtained for each worker at risk before initial assignment for such work.

b. Routine Bioassay[7]: Bioassay, including collection, evaluation, and documentation, should be performed routinely when an individual is: (1) routinely exposed to airborne yellowcake, (2) directly involved in maintenance tasks in which yellowcake dust may be produced, or (3) routinely exposed to airborne uranium ore dust.

c. Special Bioassay: Bioassay should be reanalysis or repeated, and a confirmation (validation and verification) should be performed within 90 hours of an exposure or suspected exposure equal to or above the air concentration values (based on the concentration of gross alpha activity) provided below:

(1) *Workers from Yellowcake Areas*
an average concentration of 1×10^{-10} μCi/mL (3.7 μBq/mL)[8] for a 40-hour work-week, or when air concentration data are not available

(2) *Workers from Ore-Dust Areas Exclusively*
an average concentration of 1×10^{-10} μCi/mL (3.7 μBq/mL) for a period of 3 consecutive months (90 days), or when air concentration data are not available

d. Post-Operational or Termination Bioassay: Bioassay should be performed upon completion of an individual's work assignment at a licensee's facility or when the individual worker has been terminated from tasks involving uranium assignments. The post-operational or termination bioassay sample should be performed within 2 weeks (14 days) of the operations being discontinued or the assignment terminated. A contingency plan should be developed to avoid or eliminate the failure of the last bioassay measurement.

e. Respiratory Protection Bioassay: Because the use of respiratory devices may not always offer efficient protection to workers due to defective devices or improper use, following the use of respiratory protection devices, a bioassay should be performed to verify the effectiveness of the respiratory protection devices used, and to determine the actual

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5 "Lung/thorax" measurement is based on the phantom available by the licensee to perform the direct bioassay. Although the measurement may be noted in this guide as lung count, the phantom used by the licensee could be either thorax or lung phantom.

6 Bioassay, in general, refers to either the direct or indirect measurement method.

7 "Routine bioassay" means that an individual is assigned to submit specimens (urinalysis) or lung measurements on a repeatable basis.

8 The value of 1×10^{-10} μCi/mL (3.7 μBq/mL) is not exactly consistent with the 0.2 mg/m^3 requirement for soluble uranium in Footnote 3 of Appendix B to 10 CFR 20, because of the rounding of values in Appendix B. The 1×10^{-10} μCi/mL (3.7 μBq/mL) value is the more restrictive of the two.

intake. This bioassay requirement could validate or determine whether such devices were effective.

4. **Frequency**

Routine uranium bioassay monitoring of workers, whether or not respiratory protection devices were used, should be scheduled appropriately:

a. The minimum bioassay frequency should be within the time frame provided in Table 1, "Recommended Routine Bioassay Frequency."

b. If any bioassay is positive[9] (e.g., baseline, routine, post-operational or termination bioassay) then a follow-up Special Bioassay is required.

c. The bioassay sampling frequencies are considered by the NRC staff on a case-by-case basis; however, the values in Tables A-1 and A-2 (Appendix A) are acceptable.

5. **Predetermined Action Level (PAL)**

Trained licensee personnel should promptly review the bioassay data and take appropriate action if the results exceed a PAL. The corrective actions to be taken depend on the amount of uranium content reported in bioassay measurement. Licensees may follow the recommendations in NUREG-0874, "Internal Dosimetry Model for Applications to Bioassay at Uranium Mills," (Ref. 4), regarding the frequency, types of bioassay, and recommended corrective licensee actions. If a licensee proposes different PALs and action protocols from those in Appendix A, the proposal will be considered by the NRC staff on a case-by-case basis.

a. It should be assumed that any confirmed positive urinalysis results are an indication of soluble uranium (Classes D and W) to which the kidney is exposed. The corrective actions to be taken depend on the amount of uranium detected and should be in accordance with Table A-1 of this guide.

b. It should also be assumed that positive lung count activity indicates some of Class Y uranium materials are retained in the tissue. Corrective action should be taken in accordance with Table A-2 of this guide.

c. For unlisted uranium materials licensees should:

i. For radiation protection (i.e., dose) purposes, classify the materials as inhalation Class Y.

ii. For chemical toxicity purposes (i.e., 10 CFR 20.1201(e)), classify the soluble material as inhalation Class D.

iii. Licensees can update the inhalation class of any uranium substances and materials when an appropriate analytical analysis is performed and documented.

9 "Positive bioassay" means a measurement (direct/indirect bioassay) where uranium intake has been detected.

d. Figures B-1, B-2, and B-3 (Appendix B) should be used to determine acceptable PALs for workers who were exposed in any insoluble-yellowcake area, soluble-yellowcake area, and ore-dust area, based on an acute single intake.

e. When short-lived uranium components are anticipated in urinalysis, PALs should be set based on Figures B-2 and B-3; for example, 20 μg/L from drying yellowcake operations and 1 μg/L from ore-dust workplaces at the first day or the second day post-intake, respectively.

6. **Prevention of Specimen Contamination**

d. Collection of Specimens

i. All bioassay sample or specimen should be collected in an area free of uranium before the worker enters to the work area. The collection may occur at an area inside or outside the mill that is designated specifically to be maintained free of uranium contamination. Use of disposable collection containers is highly recommended.

ii. Under any circumstances workers should either shower or wash their hands thoroughly before providing the specimen sample. When a shower is not possible, disposable plastic or rubber gloves should be worn during voiding.

iii. Sufficient urine volume should be collected to complete four separate urinalyses, each of which should be capable of achieving the required minimum quantifiable concentration value.

b. Laboratory Analysis

i. All analyses should be performed in a qualified laboratory free of uranium contamination.

ii. Both onsite and offsite laboratories should maintain the quality assurance (QA) and quality control (QC) documents as recommended in Section 7 of this guide for verification and validation purposes. The selection and use of the laboratory, sampling containers, and equipment for uranium measurements must be restricted to an ultra-low-level uranium environment.

iii. External contamination is a common source of false positive results in direct bioassay measurement. Care should be taken to minimize external contamination. All measurements that could reasonably indicate external contamination should be repeated after the individual showers and changes clothes.

7. **Quality Control (QC)**

A QC program for bioassay measurements should be established and incorporated in each uranium mill bioassay program. The programs should be consistent with the method recommended in Section 4.0, Quality Assurance and Quality Control for Radiobioassay Service Laboratory, of consensus standard ANSI/HPS N13.30-2011, "Performance Criteria for Radiobioassay." The minimum testing levels for uranium in the body through direct and indirect bioassay should be at or greater than 0.81

nano-Ci (30 Bq) and 1,000 nanograms, respectively. A program that supports estimates from urinalysis data with the in vivo determinations, or vice versa, is recommended, but not required.

8 Reports and Notifications to the NRC

If an overexposure occurs, immediate notifications and 24-hour notifications shall be made to the NRC as required by 10 CFR 20.2202. In addition, a report of the certain exposure shall be submitted to the NRC as required by 10 CFR 20.2203.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC's plans for using this regulatory guide.

Methods or solutions that differ from those described in this regulatory guide may be deemed acceptable if they provide sufficient basis and information for the NRC staff to verify that the proposed alternative demonstrates compliance with the appropriate NRC regulations. Current licensees may continue to use guidance the NRC found acceptable for complying with the identified regulations as long as their current licensing basis remains unchanged. The NRC does not intend or approve any imposition or backfit in connection with the issuance of this regulatory guide.

GLOSSARY

annual limit on intake (ALI) The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 roentgen equivalent man (rem) (0.05 sievert (Sv)) or a committed dose equivalent of 50 rem (0.5 Sv) to any individual organ or tissue.

assessment A planned and documented activity performed to determine whether various elements within a quality management system are effective in achieving stated quality objectives.

bioassay The determination of kinds, quantities, or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurement (in vivo counting) or by analysis and evaluation of materials excreted or removed from the human body (in vitro analysis).

derived air concentration (DAC) The concentration of a given radionuclide in air which, if breathed by the reference man for a working year of 2,000 hours under conditions of light work (inhalation rate of 1.2 cubic meters of air per hour), results in an intake of 1 ALI.

derived air concentration-hour (DAC-hour) The product of the average concentration of radioactive material in air during a specified period of time (expressed as a fraction or multiple of the derived air concentration) and the duration of exposure to that radionuclide in hours. The DAC-hour expresses an exposure, and 2,000 DAC-hours represent an intake of 1 ALI, equivalent to a committed effective dose equivalent of 5 rem (0.05 Sv).

direct bioassay (in vivo) Measurement of gamma or x-radiation emitted from radioactive material located within the body for the purpose of detecting or estimating the quantity (and sometimes the location) of radioactive material present.

indirect bioassay (in vitro) Measurement of radioactivity in samples of material (usually urine and feces) excreted or removed from the human body.

intake Activity that enters the body through the respiratory tract, the gastrointestinal tract, or the skin. Intake may be acute, meaning a single intake occurring over a very short time period, usually taken to be instantaneous or chronic, occurring over a specified time period. Common units used in this guide for intake are microcuries (μCi) and kilo-becquerel (kBq).

lung class It is the same as inhalation class. Solubility studies have revealed notable differences in the dissolution rates of yellowcake produced under different temperature (i.e., drying and calcining) conditions due to the variation of the density, which is associated with temperature of the unit operation. For the purpose of this guide, for bioassay interpretation and dose assessment, the following distinction is made:

- Soluble yellowcake is defined as yellowcake dried under 400 degrees Celcius (752 degrees Fahrenheit).

- Insoluble yellowcake is defined as yellowcake dried at 400 degrees Celcius or higher.

ore (uranium) The naturally occurring uranium ore materials as a mixture of uranium isotopes or natural uranium (U-nat.), it contains, by mass weight, 0.711±0.1percent of ^{235}U and assumed the ^{234}U is in equilibrium (secular) with the ^{238}U with a specific activity of 0.677 μCi/g. The radioactivity compositions are ^{235}U (2.25 percent), ^{234}U, and ^{238}U are 48.9 percent.

ore-dust areas Those areas beginning with the transfer of ore from the ore-pad to the crusher through the final thickening stage of the leaching operation, under normal conditions.

overexposure Individual doses received in excess of the annual limits listed in Title 10 of the *Code of Federal Regulations* (10 CFR) 20.1201(a), "Occupational Dose Limits for Adults."

uptake The quantity of material that enters the body fluids from the respiratory tract, the gastrointestinal tract, or through the skin. The term also is sometimes used to indicate material taken into a tissue or organ from circulation. Common units used in this guide for uptake are μCi and kBq.

yellowcake The final precipitate formed in the milling process; the composition is variable and depends on the precipitating conditions.

yellowcake areas The areas where intermediate processes take place to extract and convert the raw uranium after it has been mined and before fuel fabrication or enrichment obtained from leach solutions.

REFERENCES[10]

1. Title 10 of the *Code of Federal Regulations,* 10 CFR Part 20, "Standards for Protection against Radiation," U.S. Nuclear Regulatory Commission, Washington, DC.

2. Regulatory Guide 8.9, "Interpretation of Bioassay Measurements," U.S. Nuclear Regulatory Commission, Washington, DC.

3. Regulatory Guide 8.25, "Air Sampling in the Workplace," U.S. Nuclear Regulatory Commission, Washington, DC.

4. U.S. Nuclear Regulatory Commission (NRC), "Internal Dosimetry Model for Applications to Bioassay at Uranium Mills," NUREG-0874, Washington, DC 20555, 1986, Agencywide Documents Access and Management System (ADAMS) Accession No. ML093240418.

5. National Council on Radiation Protection and Measurements (NCRP), NCRP Report 161, "Management of Persons Contaminated with Radionuclides," Bethesda, MD 2008.[11]

6. International Commission on Radiological Protection (ICRP), ICRP Publication 30, Limits for Intakes of Radionuclides by Workers: Part 1," Pergamon Press, Oxford, England, 1979.[12]

7. ICRP Publication 54, Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation," 1st Edition, Pergamon Press, Oxford, England, 1988.

8. American National Standards Institute/Health Physics Society ANSI/HPS N13.30-2011, "Performance Criteria for Radiobioassay," McLean, VA.[13]

9. U.S. Department of Energy Standard, DOE-STD-1136-2009, "Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities," Table 2-11, Washington, DC, 2009.[14]

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10 Publicly available NRC published documents are available electronically through the NRC Library on the NRC's public Web site at http://www.nrc.gov/reading-rm/doc-collections/. The documents can also be viewed online or printed for a fee in the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is U.S. Nuclear Regulatory Commission, Washington, DC 20555; telephone 301-415-4737 or (800) 397-4209; fax (301) 415-3548; and e-mail pdr.resource@nrc.gov.

11 Copies of The National Council on Radiation Protection and Measurements (NCRP) may be obtained through their Web site: http://www.ncrponline.org/Publications/Publications.html] or by writing to the NCRP at 7910 Woodmont Avenue, Suite 400, Bethesda, Maryland 20814-3095, Ph: 301-657-2652, fax: 301-907-8768.

12 Copies of the International Commission on Radiological Protection (ICRP) may be obtained through their Web site: http://www.icrp.org/; 280 Slater Street, Ottawa, Ontario K1P 5S9, CANADA; Tel: +1(613) 947-9750 Fax: +1(613) 944-1920.

13 Copies of American National Standards Institute (ANSI) documents may be purchased through their Web site at: http://webstore.ansi.org/ or through HPS Web site at http://www.hps.org.

14 The DOE-STD-1136-2009, "Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities," DOE document may be downloaded at: http://www.hss.doe.gov/nuclearsafety/techstds/docs/standard/doe-std-1136-2009.pdf

10. ICRP Publication 66, Human Respiratory Tract Model for Radiological Protection," 1st Edition, Pergamon Press, Oxford, England, 1994.

11. ICRP Publication 68, Dose Coefficients for Intakes of Radionuclides by Workers," Pergamon Press, Oxford, England, 1994.

12. ICRP Publication 71, "Age-dependent Doses to Members of the Public from Intake of Radionuclides—Part 4 Inhalation Dose Coefficients," Pergamon Press, Oxford, England, 1995.

13. National Radiological Protection Board, Stradling, N., Hodgson, A., Ansoborlo, E., Bérard, P., Etherington, G., Fell, T., Rance, E., and Le Guen, B., "Industrial Uranium Compounds: Exposure Limits, Assessment of Intake and Toxicity after Inhalation." Report W22, National Radiological Protection Board, Chilton, England: October 2002.[15]

14. ICRP Publication 60, "1990 Recommendations of the International Commission on Radiological Protection," Pergamon Press, Oxford, England, 1991.

15. International Atomic Energy Agency, IAEA Safety Standards Series, Safety Guide No. RS-G-1.2, "Assessment of Occupational Exposure Due to Intake of Radionuclides," Vienna, Austria, 1999.[16]

15 The NRPB-W22 report may be obtainable at the National Radiological Protection Board and is available for downloading at: http://www.hpa.org.uk/Publications/Radiation/NPRBArchive/NRPBWSeriesReports/2002nrpbw022/

16 Copies of International Atomic Energy Agency (IAEA) documents may be obtained through their Web site at: http:www.iaea.org or by writing the International Atomic Energy Agency P.O. Box 100 Wagramer Strasse 5, A-1400 Vienna, Austria. Telephone (+431) 2600-0, Fax (+431) 2600-7, or E-Mail at Official.Mail@IAEA.Org

APPENDIX A
Guidelines for Uranium Bioassay Measurements

Table A-1. Corrective Actions Based on Urinary Uranium Results[a]

URANIUM CONCENTRATION	INTERPRETATION	ACTIONS
Less than 15 µg/L	Uranium confinement and air sampling programs are indicated to be adequate.[b]	None. Continue to review further bioassay results.
15 to 35 µg/L	Uranium confinement and air sampling may not provide an adequate margin of safety.[b]	1. Confirm results (repeat urinalysis). 2. Identify the cause of elevated urinary uranium and initiate additional control measures if the result is confirmed. 3. Examine air sampling data to determine the source and concentration of intake. If air sampling results are anomalous, investigate sampling procedures. Make corrections if necessary. 4. Determine whether other workers could have been exposed and perform bioassay measurements for them. 5. Consider work assignment limitations until the worker's urinary concentration falls below 15 µg/L of uranium. 6. Improve uranium confinement controls or respiratory protection program as investigation indicates.
Greater than 35 µg/L	Uranium confinement and/or air sampling programs are not acceptable.[c]	1. Take the actions stated above. 2. Continue operations only if it is virtually certain that no other worker will exceed a urinary concentration of 35 µg/L of uranium. 3. Establish work restrictions for affected employees or increase uranium confinement controls if ore dust or high-temperature-dried (HTD) yellowcake are involved. 4. Analyze bioassay samples weekly.
Confirmed to be greater than 35 µg/L for two consecutive specimens, confirmed to be greater than 130 µg/L for any single specimen or air sampling indication of more than a quarter of (i.e. ¼) the ALI.	Worker may have exceeded regulatory restrictions on uranium intake.	1. Take all appropriate actions stated above. 2. Have urine specimen tested for albuminuria. 3. Obtain an in-vivo lung count if the worker may have been exposed to Class Y material or ore dust. 4. Evaluate exposures. 5. Establish further uranium confinement controls or respiratory protection requirements as indicated. 6. Consider continued work restrictions for affected employees until urinary elimination is below 15 µg/L and laboratory tests for albuminuria are negative.

a. Use figures in Appendix B to adjust action-levels for other frequencies of bioassay sampling. The model used in NUREG-0874 employs fractional composition values (F_1, F_2, F_3) for Class D, Class W, and Class Y components of yellowcake compounds. The assigned values in NUREG-0874 are based on data from available literature. The use of alternative values of F_1, F_2, and F_3 specific for a particular operation are acceptable provided that (1) details regarding their determination are described and mentioned in employee exposure records (see 10 CFR 20.2106(a)(4)) and (2); the model as published in NUREG-0874 is then used in the determination of alternative urinalysis frequencies and action-levels.

b. However, if a person is exposed to uranium ore dust or other material of Class W or Y alone, refer to Section 6 of NUREG-0874 regarding the possible need for conducting in-vivo lung counts on selected personnel or using alternative urine sampling times and associated action-levels computed using NUREG-0874.

c. Unless the result was anticipated and caused by conditions already corrected.

Table A-2. Corrective Actions Based on Direct Bioassay (In Vivo) Results[a]

URANIUM IN LUNG	INTERPRETATION	ACTIONS
Below 9 nCi (330 Bq)	May be below detection limit. This result does not necessarily indicate that uranium confinement and air sampling programs are validated.	Rely on urinalysis results to determine corrective actions (unless air sampling indicates 500-DAC is exceeded for ore dust).
9 to 16 nCi (330 to 590 Bq)	Confinement and air sampling programs should be examined.[b] Uranium activity in lungs could be too high.	1. Confirm result (repeat measurement). Ensure that results are not caused by body surface activity. 2. Examine air sampling data to determine source and concentrations of intake. If air sampling results are anomalous, investigate air sampling procedures. Make corrections, if necessary. 3. Identify the cause of elevated activity and initiate additional uranium confinement control measures. 4. Determine whether other workers could have been exposed and perform special bioassay measurements for them. 5. Consider work assignment limitations that will permit the lung burden to be reduced through natural elimination; ensure that the lung burden does not exceed 16 nCi (590 Bq).
More than 16 nCi (590 Bq)	Uranium confinement and air sampling probably are not acceptable.[b] Uranium activity in the lungs should be reduced by increased protection measures for the workers involved.	1. Within 30 days, take the actions listed above for 9 to 16 nCi (330 to 590 Bq). 2. Establish work restrictions for affected workers or increased uranium confinement control measures. (Normally workers with a lung burden greater than 16 nCi (590 Bq) are not allowed by their employer to resume work in airborne activity areas until the burden is reduced to less than 9 nCi or 330 Bq.) 3. Perform individual case studies (bioassays) for affected workers. 4. Continue operations only when it is virtually certain no additional workers will exceed 16 nCi (590 Bq).

a. The model used in NUREG-0874, "Internal Dosimetry Model for Applications to Bioassay at Uranium Mills," uses fractional composition values (F_1, F_2, F_3) for Class D, Class W, and Class Y components of yellowcake compounds. The assigned values in NUREG-0874 are based on data from available literature. The use of alternative values of F_1, F_2, and F_3 specific for a particular operation are acceptable provided that (1) details regarding their determination are described and mentioned in employee exposure records (see 10 CFR 20.2106(a)(4)) and (2) the model as published in NUREG-0874 is then used in the determination of alternative urinalysis frequencies and action-levels.

b. Unless the result was anticipated and caused by conditions already corrected.

APPENDIX B
Data Supporting Corrective Action Levels Following a Single Acute Intake

Figure B-1.
Uranium Concentration in Urine Following Inhalation Exposure of 1 ALI to Calcining Yellowcake (NUREG-0874)
(1 ALI = 160,000 µg U)

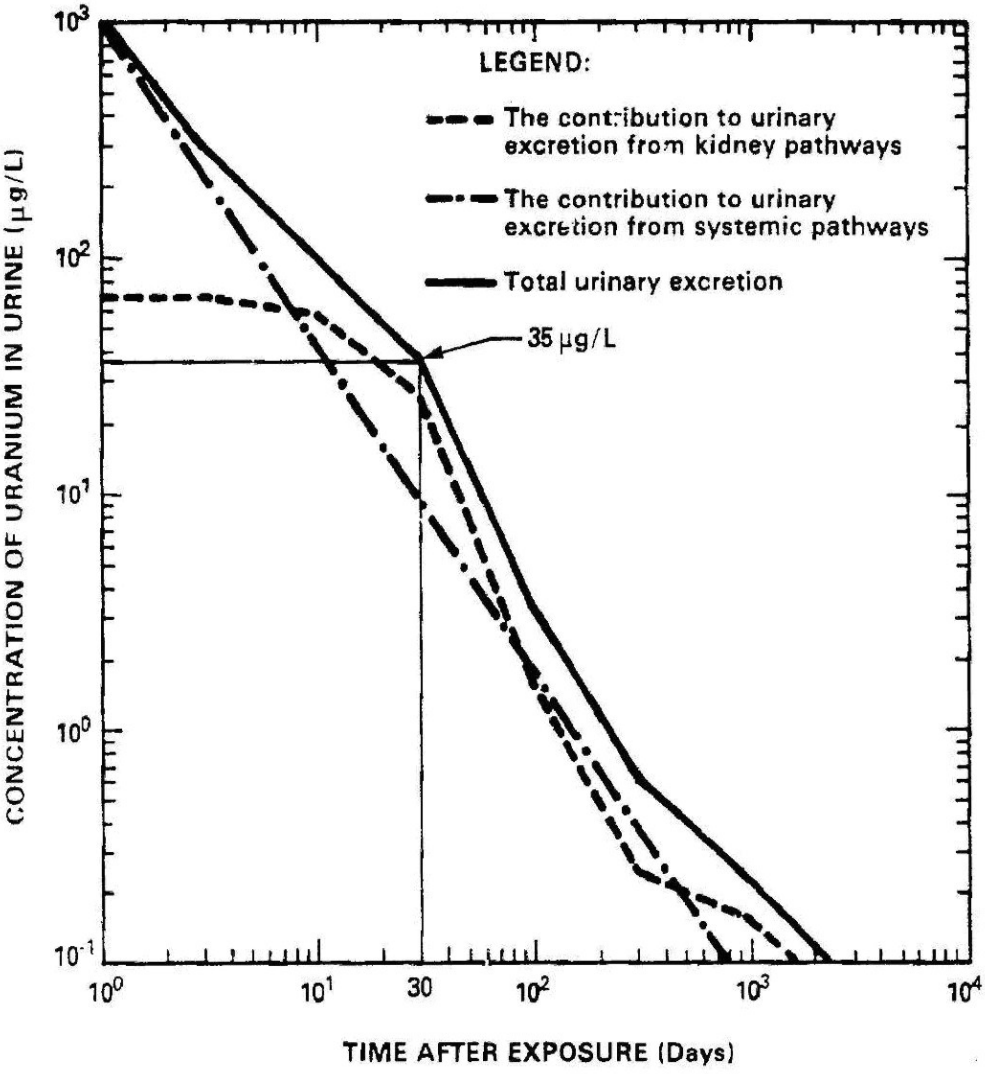

Figure B-2.
Uranium Concentration in Urine Following Inhalation Exposure of 1 ALI to Drying Yellowcake (NUREG-0874)
(1 ALI = 260,000 µg U)

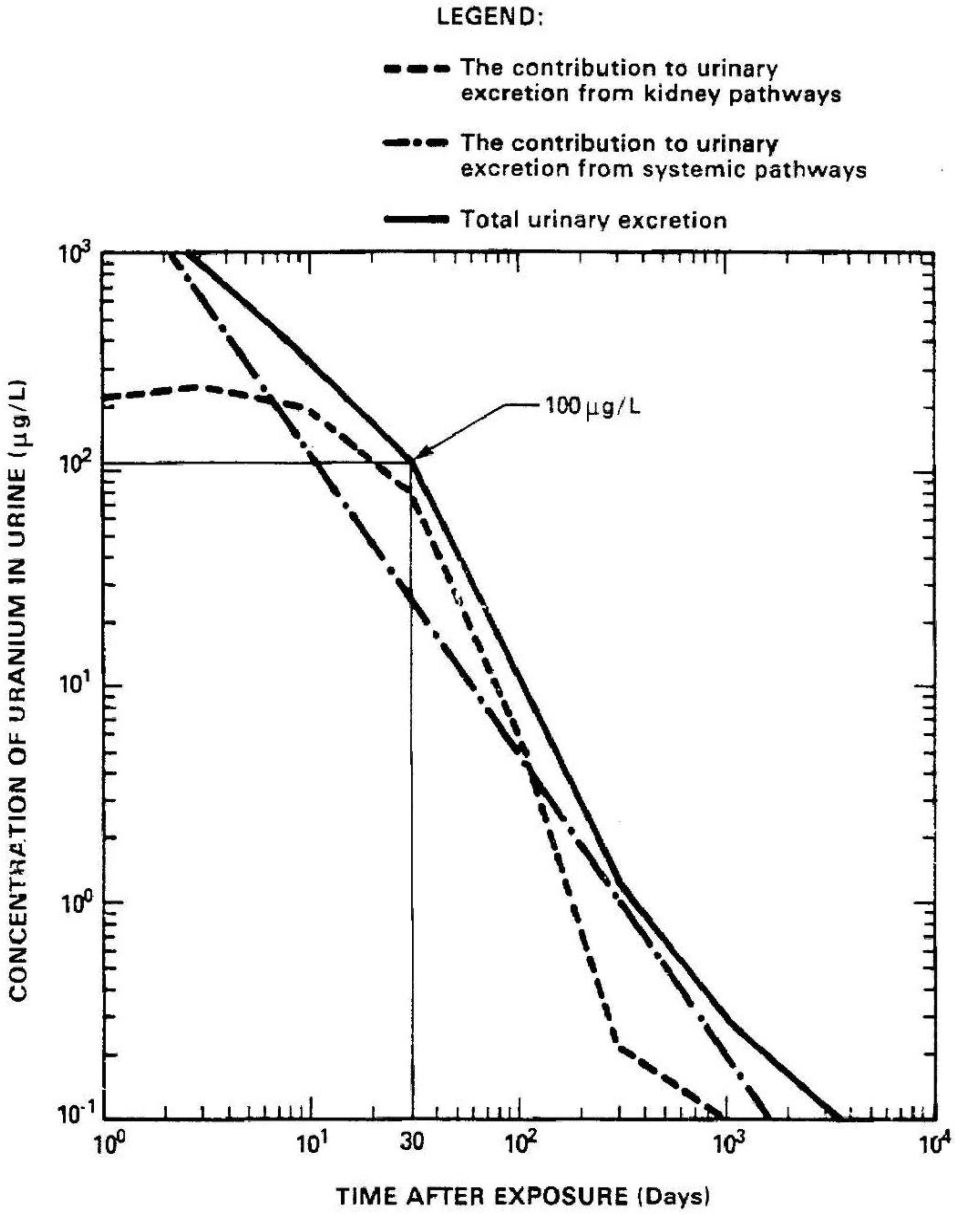

Figure B-3.
Uranium Concentration in Urine Following Inhalation Exposure of 1 ALI to Ore Dust (NUREG-0874)
(1 ALI = 46,000 μg U)