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6. Effluent Monitoring and Environmental Surveillance

Operators in the mineral extraction industries should monitor releases of radioactive materials to the environment to determine radiation exposures, define the extent of contamination, determine compliance with government regulations and corporate guidelines, and provide a basis for assessing the efficiency of effluent control systems. In this Section, environmental and effluent monitoring programs are presented, based on radiation protection principles. Additional monitoring may be required or prudent at specific facilities based on site-specific conditions.

Criteria are presented in this Section to determine the need for limited or routine environmental monitoring. However, before a mineral extraction facility is built, baseline environmental samples should be collected. Those samples are used to document the radionuclide concentrations present prior to the operation of the facility and to segregate facility-induced conditions from pre-existing conditions, including those from other facilities. The analysis of air, water, soil and vegetation samples is recommended for radionuclides and for chemical elements that have a known or potential influence on the bioaccumulation of radionuclides in plants or animals.[4] This is important for adequate evaluation of potential impacts since the uptake of nonessential radionuclides may be strongly influenced by the abundance or scarcity of an essential chemical element analog (Vanderploeg *et al.*, 1975). For example, if radium in water is an effluent from the facility, the analysis of calcium in the receiving waters or soil is advisable because the uptake of radium by plants or animals has been observed to be influenced by the availability of calcium (Hansen *et al.*, 1960; Lindeken and Coles, 1978).

The program for the collection of baseline data typically requires compilation of up to one year's data for comparison with the data collected during operations. If seasonal trends are observed in the

[4]See Section 6.3.2 for additional information on baseline program design and compatibility with operational monitoring.

baseline concentrations, those concentrations can be used to adjust the data collected during operations to obtain a measure of facility effluents present in the environment.

6.1 Environmental Pathways

Figure 6.1 presents the principal potential radiological exposure pathways to humans from mineral extraction operations. (Other pathways may exist at some facilities, for example, release from tailings impoundments to surface water.) The effluents from the sources on the left side of the figure may enter the atmosphere, surface water or groundwater where dilution, dispersion, concentration, reconcentration, deposition or resuspension may occur; radioactive ingrowth and decay may occur as well. Ultimately, a portion of the radioactive materials may be transferred to humans from the environment. Once the materials are inside the human body, radiological exposure to the whole body and to individual organs occurs. The degree of exposure is dependent on the individual radionuclide,

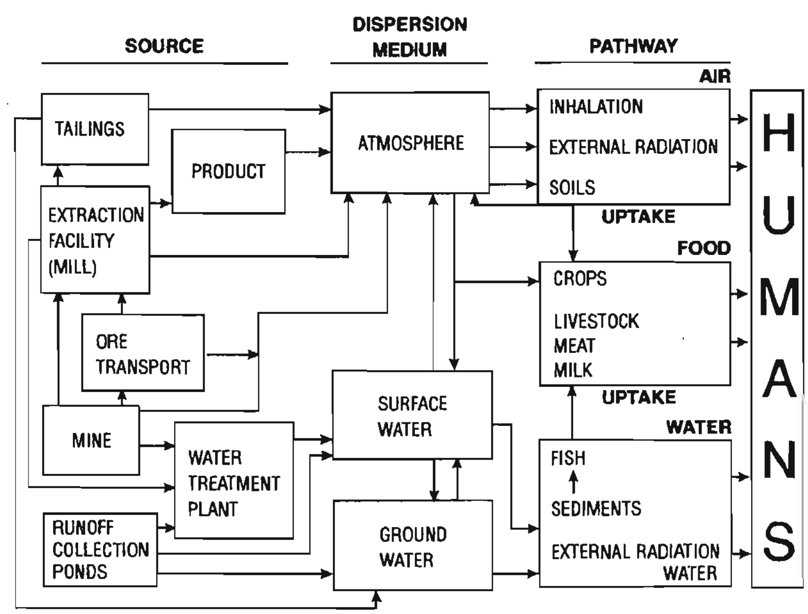

Fig. 6.1. Principal radiological exposure pathways to humans from mineral extraction industries.

its chemical and physical form, its concentration and how it is metabolized. Further details can be found in NCRP Report No. 76 (NCRP, 1984b) and IAEA Safety Series Nos. 77 and 90 (IAEA, 1986; 1989).

6.2 Effluent Monitoring

6.2.1 *Effluent Monitoring Objectives*

Specific objectives to be met by the design of each monitoring and surveillance program include:

(1) collection of representative samples of effluents at a frequency that will allow corrective actions prior to any significant environmental contamination or radiological exposures.

(2) collection of representative samples at locations that allow assessment of environmental impacts. Usually such locations are at or near the point of release to the environment, for example, in a mill scrubber stack or at the discharge pipe from a mine water treatment plant. Detection of radionuclides is easier at such locations because dilution and dispersion in the environment have not yet occurred.

(3) analysis of the collected data for trends of increasing or decreasing concentrations as a function of the time of collection to determine whether changes in monitoring programs or effluent controls are warranted. Trends should be reviewed annually or at a frequency which correlates with major repairs or changes in equipment that could impact effluent concentrations.

(4) assurance to the public that all significant impacts resulting from the operation of the facility are being monitored and analyzed.

(5) validation of the measured values by documentation of the sampling and analytical procedures and quality assurance measures.

6.2.2 *Program Design*

The necessity for effluent monitoring should be assessed initially and at least when there are changes in equipment that could affect effluent concentrations. Facility operators need to know or determine the radionuclide content and concentration in each process circuit, points within the circuits where radionuclides can concentrate, points of potential releases to the environment and the radionuclide concentrations that could be or are present in effluent streams. Consideration should be given to the potential for release of radionuclides to the environment *via* pathways such as sanitary or storm sewers in addition to the direct process-circuit pathways. Those data are used to provide an estimate of effluent concentrations in the environment[5], an estimate of the effective dose (radiation dose from effluents released to the environment), and a list of radioactive materials to be measured in the effluent and environmental monitoring programs (see Section 6.3.2). The NRC has reported on effluents from uranium mines and mills and has estimated doses to residents near those facilities from those effluents (NRC, 1980). Such information may supplement site-specific information in defining effluent program design. Also, guidance is emerging on approaches to demonstrate compliance with EPA emissions standards (Rhodes, 1992).

Effluent monitoring should continue in effect when potential doses are greater than ten percent of the nonoccupational dose limits.[6] When ongoing effluent monitoring is warranted, the interpretation of data must be considered. Large area sources, multiple release points and short sampling times relative to long effluent-discharge time periods each introduce complexities in interpretation of environmental data. The monitoring program design should minimize uncertainties of data interpretation. Site-specific validation of environmental assessment models is recommended as a complement to the effluent monitoring program design. To ensure meaningful evaluation of the directional transport and dispersion portions of the model, assistance from qualified individuals may be required in designing an effective validation test.

6.2.3 *Air Monitoring*

Airborne emissions from underground mines occur at the mine ventilation shafts. Usually ventilation air is brought into the mines through the equipment-ore haulage shaft, routed to the working areas of the mine and exhausted through several ventilation shafts

[5]Calculational models are often used to estimate environmental concentrations resulting from concentrations in effluent. Use of such models typically requires knowledge of site-area meteorological data (*e.g.*, wind speed, wind directions and temperatures). Such data may be obtained from meteorological towers constructed on-site for that purpose or from other information sources believed to be representative of site-area conditions.

[6]Nonoccupational dose limits are presented in NCRP Report No. 116 (NCRP, 1993) or are established by regulation (see Section 7.)

located away from the main haulage shaft. The extensive atmospheric dispersion induced by the high velocity discharge from those ventilation shafts normally results in site-boundary concentrations which are indistinguishable from background levels. Thus, a monitoring program for the exhaust air would be appropriate for underground mining operations when members of the general public live nearby. For operations remote from the general public, a monitoring program for exhaust air is not recommended. Monitoring of airborne effluents from open pit mines is not usually warranted because of the large surface area available for release of effluents and the large atmospheric dispersion associated with open pit mines. Again, monitoring would usually result only in background-level measurements and confirm the limited potential for exposure of members of the public.

The highest concentrations of airborne effluents from mills are usually from the mill exhaust stacks. The stacks most likely requiring monitoring are those that release effluents which could result in significant exposures to humans *via* direct inhalation [NCRP (1993) presents recommendations on limits for exposure to ionizing radiation]. Such exhaust stacks include those from the yellowcake dust collector at uranium mills. Isokinetic sampling through monitoring ports installed in the side of such stacks is recommended (EPA, 1985). For stack effluents that produce lower potential exposures, less precise and simpler measurements, such as grab sampling using portable equipment, are useful in determining whether the stacks contribute significantly to the airborne radionuclide emissions from the facility. The screening models discussed in the next section will help determine the significance of the stack emissions.

The frequency of monitoring is a function of the potential for a release from the facility, the potential impact of the effluent on people and the environment and the variability in release rate over time (including the reliability of the effluent control system). When exposure or concentration limits are being approached or a significant potential for a large release exists, the sampling should be done frequently, possibly continuously. As an alternative to a statistical evaluation of the sampling frequency and total number of samples necessary for specific circumstances, Table 6.1 is presented as a guide for a stack sampling program at a uranium mill, which may represent a worst-case situation for the minerals extraction industry. Other facilities, which may have smaller quantities of radionuclides or have a lower potential for a large release, may require less frequent sampling. Sufficient sample volumes need to be collected to meet the lower limits of detection (LLD) of the analytical laboratory and as specified in the applicable regulations. Where practica-

TABLE 6.1—*Stack monitoring frequencies and sample types for a typical uranium mill.*

Effluent control equipment	Materials controlled	Potential exposure	Operational check frequency[a]	Stack monitoring frequency	Special monitoring requirements
Wet scrubber	yellow-cake	high	hourly or continuous	quarterly	isokinetic
Bag dust collector	U ore dust	moderate	monthly	semi-annually	—
Mist eliminator	acid mists from U ore leach tanks	low	annually	one time only	—

[a] An operational check is a test of the effluent control equipment to ensure that it is functioning as designed. Selection of the type of check depends on the design and reliability of the equipment and the need to ensure that effluent controls are at least as effective as assumed in environmental assessment modeling.

ble, multiple samples should be collected and analyzed, to provide a higher level of confidence in the results [see NRC Regulatory Guide 8.30 (NRC, 1983a) and NCRP Report No. 58 (NCRP, 1985a)].

6.2.4 *Water Monitoring*

Water containing radionuclides may potentially be released to constructed ponds, surface waters or waterways. The subsequent fate of the radionuclides is indicated by the exposure pathways presented in Figure 6.1.

Representative grab samples of water effluent should be obtained at the point of release from mineral extraction facilities. That point is often the pipe releasing water from the water settling ponds or from the water treatment plant. The analyses of both suspended and dissolved constituents are recommended where both water fractions can transport radionuclides to people or the environment. The frequency of sampling may be determined as described in Section 6.2.3. For facilities with reasonably stable release rates, monthly composite samples consisting of at least three samples may be sufficient. Automatic, continuous, water samplers are available and can facilitate the sampling tasks [see NRC (1983b) for suggested LLD values].

6.3 Environmental Surveillance

6.3.1 *Environmental Monitoring Objectives*

The objectives of an environmental monitoring program for radiation protection are:

(1) to assess the radiation and radionuclide levels in the preoperational environment,

(2) to detect changes in levels to verify the adequacy of effluent assessment and control programs and to evaluate loss of control,
(3) to assess actual or potential exposure of members of the public from facility effluents and from direct (γ-ray) radiation from the facility,
(4) to determine the fate of contaminants released to the environment, and
(5) to demonstrate compliance with applicable regulations or other legal requirements.

In achieving these objectives, the facility operator is able to provide assurance to the public that potentially significant impacts are being monitored and analyzed.

6.3.2 *Program Design*

In 1984, the NCRP published a statement concerning the proposals made by EPA under 40 CFR 61 on the control of air emissions of radionuclides (NCRP, 1984d). This statement reviewed existing limits in published NCRP reports and works in progress and emphasized that for continuous exposure of an individual in the population an annual effective dose of 1 mSv should be limiting. The statement went on to say that whenever the potential exists for an individual to exceed 25 percent of the limit for whole body exposure from any single site, the site operator should be required to assure that the annual whole-body effective dose of the maximally exposed individual from all sources would not exceed 1 mSv on a continuous basis.

The operator of a mineral extraction facility needs to determine appropriate means to assess exposure of individuals and more specifically the need to conduct environmental radiation monitoring prior to and/or during facility operations as a means of exposure assessment. Screening models may be used to help operators determine if an environmental monitoring program should be conducted during facility operations. Note that exceeding a screening level does not imply any noncompliance with regulations or limits.

The screening model set out in NCRP Commentary No. 3 (NCRP, 1989b) is limited to routine operational releases of specific radionuclides to the atmosphere over a period of one year. If the calculated radiation doses to individuals as determined using the screening model do not exceed the nonoccupational dose limits[7] at any succes-

[7]Nonoccupational dose limits are presented in NCRP Report No. 116 (NCRP, 1993) or are established by regulation (see Section 7).

sive level in the model, environmental monitoring during operations is not considered necessary. Conversely, if the calculated screening value exceeds the applicable nonoccupational dose limit at the final level of screening, then an environmental monitoring program is recommended. A similar methodology is described by the EPA (1989a) to demonstrate compliance with the rules of 40 CFR 61 (EPA, 1989b).

When airborne radioactive materials other than those presented in the screening model (NCRP, 1989b) are released from the facility or when radioactive materials are released into a water pathway, the following screening mechanisms may be used to determine the necessity of environmental monitoring during operations.

(1) If the concentrations of radionuclides in water or air as measured *at the discharge points* from the facility are calculated to result in a committed effective dose of less than 1 mSv in a year, environmental monitoring is not necessary since distance between the discharge points and the location at which an intake would usually occur dilutes the effuents to concentrations below which environmental monitoring is recommended.

(2) In the unusual case where the public has access to air or water directly at the discharge point, initiation of environmental monitoring would be appropriate because the dilution factor mentioned above would not be applicable.

(3) If the concentrations measured at the discharge points are calculated to result in an annual dose higher than the 1 mSv committed effective dose limit, environmental monitoring is recommended.

This method of determining the necessity of environmental monitoring is at least four times more restrictive than the first level of screening for atmospheric releases set out in NCRP Commentary No. 3 (NCRP, 1989b). The NCRP plans to publish a comprehensive screening model report for more than 800 radionuclides, and for both air and water pathways. For those facilities for which environmental monitoring during operations is recommended, baseline (preoperational) environmental monitoring is also recommended. Such monitoring enables appropriate consideration to be given to preexisting conditions on and near the site of the facility.

If the screening results in a determination that ongoing environmental monitoring is *not necessary*, the facility operator should still evaluate the *desirability* of conducting environmental monitoring prior to and/or during operations. Objectives of environmental monitoring programs remain valid even when the probable upper limit of exposure has been reasonably estimated and compliance with regulations is reasonably assured. Corporate philosophy regarding scientific investigation and provision of additional levels of assurance of facility safety may lead to the decision to perform monitoring. For example, monitoring may be determined to be prudent to verify the applicability of the screening model to site-specific conditions. Similarly, performance of monitoring may be determined to be prudent to ensure preexisting conditions are properly considered in facility operations.

If the decision has been made to conduct environmental monitoring, samples representative of environmental concentrations need to be collected. Sampling usually extends over the duration of at least one year to demonstrate possible seasonal variations. If the potential radiation doses to individuals attributable to facility effluents and calculated from the results of environmental sampling are ten percent or less of the nonoccupational dose limits, continued environmental monitoring may not be needed. Such a decision should be reevaluated if changes in the extraction facility are made which would increase the actual or potential effluents or if more than one source exists in the area. Then, environmental monitoring should continue consistent with the criteria described above and with corporate policy. The environmental monitoring should be for those radioactive materials in each major pathway that would be expected to contribute substantially to the calculated radiation dose.

Effluent monitoring, such as stack or water discharge monitoring, continues when potential doses are greater than ten percent of the nonoccupational dose limits. Then, environmental monitoring should also continue, to provide assurance that corrective actions could be implemented before the nonoccupational dose limits are exceeded.

In the design of an environmental monitoring program, the baseline environmental monitoring program and the operational program should be made as compatible with one another as possible. For example, using as many of the same sampling locations as possible allows direct comparison of the data collected to assess conditions before and after facility operations commence. Sampling of the following types of media, representative of major pathways in environmental monitoring programs, is recommended in the baseline and the operational monitoring program:

(1) airborne particulate material, gases and gamma radiation near the site boundaries of the property, as determined by fencing and posted signs, and in the directions that have the highest predicted concentrations of airborne particulates;

(2) airborne particulate material, gases and gamma radiation near the closest residence or structure that is occupied for a

portion of each year and near the residence that has the highest anticipated concentrations of airborne radionuclides, *e.g.*, the nearest residence and the nearest downwind residence;

(3) airborne particulate material, gases and gamma radiation at the nearest population center that could be affected by the facility;

(4) water samples from the uppermost aquifer that is, or could potentially be used as, a water source and is hydrologically down gradient from major potential sources of seepage, such as tailings ponds;

(5) water samples from at least one downstream surface water sampling point or from potentially affected surface water ponds;

(6) human food crops, fish (if applicable) and livestock feed samples from locations where the highest airborne radionuclide concentrations are predicted;

(7) soil samples from areas of the highest predicted airborne radionuclide concentrations;

(8) all sample types at control locations upwind, upstream or up groundwater-flow gradient from the extraction facility and sufficiently distant so as not to be affected by facility operations, yet in the same airflow patterns, stream or aquifer as is sampled above.

Analyses requested on samples from the selected locations should be based on the radioactive materials to be released from the facility and their expected contribution to radiation dose, as well as the chemicals and metals associated with the ore or extraction process, and their expected contribution to environmental impact. Consideration may also be given to infrequent screening analyses for other radionuclides, chemicals and metals, to verify that they are not found in unexpected concentrations.

In the environmental monitoring program, the selection of monitoring locations is often complicated by site-specific topography, demography and the proximity of one facility to other similar facilities. For example, the presence of deep canyons or valleys near the facility can cause elevated concentrations of airborne effluents as diurnal winds move up and down the valley or canyon. If residences are located in those canyons or valleys, higher than normally expected exposures may occur at those locations.

During emergencies, such as large spills or releases to the environment, sampling and monitoring should begin as soon as possible. If possible, samples should be collected as a function of both time and distance and from sample locations identified in advance of an emergency. In general, more samples should be collected and preserved, if applicable, than is deemed necessary at the time of the incident. The number of samples to be analyzed can be determined at a later time.

6.3.3 *Radon*

If integrated or continuous sampling techniques are not used, radon sampling can be very time-consuming due to the numerous samples needed to characterize the natural variability of radon concentrations. Radon monitors using TLD or etched-track integration techniques are recommended to determine radon concentrations. In general, monitors using the TLD system perform better in dry climates than in wet climates. The etched-track system may require visual counting of etch marks in the detector to measure radon concentrations. Human error (fatigue) associated with the visual counting is then a factor to be included in the interpretation of results. For a discussion of radon dosimetry see NCRP Report No. 77 (NCRP, 1984a). For a detailed discussion of radon measurement techniques see NCRP Report No. 97 (NCRP, 1988c).

Radon flux (exhalation rate per unit area) measurements may be used to define a radon source term for an extended source such as a tailings pile, but numerous replicate samplings in time and location are necessary to establish long-term average radon emissions. Further, the techniques used for flux measurements disturb the system being measured (NCRP, 1988c). Flux characterization may be of some value in a reclamation program or in tests using specific regulatory-agency dispersion models but is not recommended as a component of an effluent monitoring or environmental monitoring program.

6.3.4 *Radon Progeny*

Radon progeny concentrations are not routinely measured in the outdoor environment because of the dilution of radon progeny that occurs outdoors. (The magnitude of the exposure received outdoors from radon progeny is only a small percentage of the potential indoor exposure levels.) Radon measurement is easier for continuous or integrated sampling, and calibration and quality control are more readily achieved for radon (versus progeny) measurements (NCRP, 1988c). Accordingly, radon progeny measurements outdoors are not considered a necessary component of an environmental monitoring program at mineral extraction facilities.

6.3.5 *Long-Lived Airborne Radionuclides*

Low-volume air sampling at approximately 0.002 m^3 per s is recommended for particulate air sampling because of the low maintenance requirements of the samplers as compared to that for high-volume air samplers operated at approximately 0.02 m^3 per s. Each unit should be equipped with an air flow regulator and an elapsed time meter which allows determination of the volume of air actually sampled even if power failures occur. If particle sizing is needed, sampling equipment appropriate for that purpose would need to be used.

6.3.6 *Soil and Vegetation*

Terrestrial and other types of environmental sampling are addressed in NCRP Report No. 50 (NCRP, 1976). The need for soil and vegetation sampling is usually site-specific to each mining location and is based on the potential exposure pathways that are identified (Figure 6.1). For example, if cows graze near the facility, sampling grasses in the predominant wind direction may be appropriate. One factor of importance is that the sample size for both soil and vegetation sampling should be large enough to collect sufficient activity for analysis. See NRC Regulatory Guide 8.30 (NRC, 1983a) for the calculation of the LLD based on sample size.

6.3.7 *Water*

Sampling of water both on the surface and within the ground requires the collection of nonstagnant water samples. If samples are pumped, as from a well, the electrical conductivity of the water should have stabilized prior to sample collection to acquire a representative groundwater sample. Preservation of the samples is essential to prevent plateout of radionuclides like ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po on the walls of the container (Korte and Kearl, 1984). Care should be taken to ensure that the preservation technique does not result in dissolution of the suspended component of the radionuclide concentrations. Surface water should be analyzed for both suspended and dissolved radionuclides, whereas groundwater normally should be analyzed for only the dissolved fraction. That fraction acts as the transfer medium of radioactive materials to plants, animals and man, and its analysis predicts more closely the potential for exposure through ingestion pathways. (In those cases where unfiltered water is consumed, analysis of the suspended fraction may be appropriate.)

Chemical analyses of water samples are often included in groundwater monitoring programs to predict the movement of radionuclides through aquifers. The analysis of relatively mobile groundwater constituents, such as chloride, sulfate and total dissolved solids, can be used to determine the rate and direction of the migration of a seepage plume.

6.3.8 *External Radiation*

When higher-than-background gamma-ray levels are present in the environment around a facility, and these levels can be attributed to the facility, gamma monitoring is recommended. TLDs are recommended for gamma detection and are usually placed in circular patterns around the radiation source at the facility. The TLDs should be exchanged every three to six months. That frequency is sufficient to allow detection of greater than the lower limit of detection for gamma radiation yet guards against the physical loss of detectors integrating exposures over long time periods.