Safety Reports Series

No.27

Monitoring and Surveillance of Residues from the Mining and Milling of Uranium and Thorium

International Atomic Energy Agency, Vienna, 2002

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MONITORING AND SURVEILLANCE OF RESIDUES FROM THE MINING AND MILLING OF URANIUM AND THORIUM

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FOREWORD

The conventional mining and processing of uranium and thorium ores generate large amounts of waste material. Mine operations generate overburden, barren waste rock and mineralized waste. Uranium and thorium mills process the mined material by milling and chemical leaching, and typically produce a residual sand-like material or silty tailings from which uranium and/or thorium has been extracted. In cases where ore extraction is performed using in situ leaching techniques, the barren host material resides in its original locations but is chemically altered. Whichever process is used, some of these materials are radiologically and chemically hazardous and need to be controlled.

Safety in the management of radioactive wastes from the mining and milling of ores is the subject of the IAEA Safety Guide WS-G-1.2 (Management of Radioactive Waste from the Mining and Milling of Ores). Important components of safe management are the design and implementation of programmes for the monitoring and surveillance of the residues from mining and milling operations. This Safety Report provides technical information on the development of effective monitoring and surveillance programmes.

This Safety Report was developed through a series of consultants meetings. The IAEA wishes to express its gratitude to all those who assisted in its drafting and review. The IAEA technical officer responsible for the preparation of the report was D. Reisenweaver of the Division of Radiation and Waste Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The mining and processing of uranium and thorium bearing minerals generate a variety of waste materials containing a number of radioactive and non-radioactive hazardous constituents. Conventional underground and open pit mining activities produce overburden, mineralized waste and barren waste rock, which are generally low in their uranium and thorium contents and are left at the mine site. Economically valuable ore is stockpiled and processed at the mill site, and the residual waste, mostly mill tailings, is normally disposed of near the mill site; this waste requires appropriate management. Because some of the radionuclides contained in the various waste streams have long half-lives (>1000 years), the final disposal facilities have to be effective for long periods of time. This is typically achieved by placing the waste material back into the open pits or underground workings, or by placing the material in above ground surface impoundments.

In situ leaching is an alternative method of extracting uranium and thorium. This process does not physically remove the host material from its underground location, but preferentially extracts the uranium by solution mining and leaves the 'tailings' in their original subterranean location. No significant quantity of solid waste is generated at the surface with this method.

In all cases, the original host material is altered physically (crushing for conventional mining) and/or chemically (conventional milling and in situ leaching) to extract uranium. At each process phase, environmental media (e.g. air, surface water, groundwater) may interact with the material and potentially disperse contaminants to human and environmental receptors.

The safe management of uranium and thorium mining and milling waste requires that monitoring and surveillance be conducted throughout the life of the waste management facility[1] (see Figs 1–3). Monitoring, in this context, is the measurement of radiological, environmental and other parameters and forms a basis for assessing the effectiveness of the waste management practices. It serves a number of purposes including providing for the verification of environmental impact predictions, demonstrating compliance with regulatory requirements and for providing data from which radiation doses to the relevant critical groups in the population may be assessed. Monitoring may also provide an early warning of abnormal changes in the

[1] For the purpose of this Safety Report, a waste management facility is defined as a mine, pit or above ground impoundment that contains radioactive residue from mining and milling activities for uranium or thorium ores.

waste management system and be used to provide information and reassurance to the public.

Surveillance, in the context of this document, means physical inspection to verify the integrity of the waste management facilities. Information obtained from the monitoring and surveillance programme is used to assess the potential impacts of waste management practices and may be used in the design and implementation of controls to reduce adverse environmental impacts.

The Safety Guide on Management of Radioactive Waste from the Mining and Milling of Ores [1] provides guidance on the strategies and protocols for siting, design, construction, operation and closure of radioactive waste facilities from mining and milling. This Safety Report elaborates on the basic recommendations relating to monitoring and surveillance as set out in the Safety Guide.

1.2. OBJECTIVE

The objective of this Safety Report is to describe the features of the monitoring and surveillance programme that are considered necessary for the safe management

FIG. 1. Unstabilized tailings pile.

of radioactive residues generated in the mining and milling of uranium and thorium ores. The Safety Report is intended to help operators, regulators and licensees of mining and milling facilities by aiding them in establishing and implementing appropriate monitoring and surveillance programmes. In fulfilling this objective, the document is elaborating on the recommendations set out in the Safety Guide on Management of Radioactive Waste from the Mining and Milling of Ores [1].

1.3. SCOPE

This Safety Report describes current methods of environmental monitoring and physical site surveillance applicable to the management of uranium and thorium

FIG. 2. Tailings pond in operation.

mining waste disposed of in underground mines, open pits and at the surface. Information is also presented that is applicable to the management of waste from in situ leach mining operations.

Consideration is given to environmental monitoring and site surveillance in all phases of the mining, milling and leaching operations for uranium and thorium, from the pre-operational to the post-closure phase. The report concentrates on radiological aspects, although some consideration is given to non-radiological monitoring as it is often performed simultaneously and may provide additional information which can assist in radiological assessment. Monitoring as part of occupational radiation protection is detailed in other IAEA publications [2–4] and is consequently not discussed in this Safety Report. Much of the information presented in this Safety Report may also be applicable to other mining operations that produce tailings as a by-product containing elevated levels of radioactive material, such as those engaged in phosphate, gypsum and rare earth extraction.

FIG. 3. Tailings pond no longer in operation.

1.4. STRUCTURE

The Safety Report is structured as follows. Section 1 contains background information, and details the objective, scope and structure of the Safety Report. Section 2 identifies the major mechanisms by which the contaminants can be released from the mill tailings and mine waste. Section 3 discusses the two types of initial environmental survey and the importance of each survey. Section 4 discusses the purpose and content of a good monitoring programme and identifies the techniques that can be used to monitor each effluent. Section 5 describes a typical surveillance programme for the site and the techniques used to control the site. Section 6 discusses the reporting and archiving of documentation. Section 7 provides information on quality assurance requirements. Section 8 provides a summary and conclusions related to the monitoring and surveillance processes.

Three annexes provide additional information. Annex I provides an example of the type of information to be included in a long term surveillance plan for a uranium mill tailings site in the post-closure phase. Annex II is an example of a checklist that can be used when performing a physical inspection or conducting surveillance of a waste management facility for above ground mill tailings. Annex III provides an example of a photographic log that can be used in site surveillance.

2. MODES OF POTENTIAL RELEASE OF CONTAMINANTS FROM MILL TAILINGS AND MINE WASTE

Uranium and thorium mill tailings, mine waste and contaminants may be released to the environment by a number of different processes. Once released, these materials can reach humans by a variety of environmental pathways. Because these releases may occur during any stage of the mining and milling operations, it is important to maximize the final environmental isolation of all waste material throughout the life of the operations and not only when the mining and processing activities end. Figure 4 illustrates the conceptual exposure pathways for a typical tailings or mine waste pile.

The dominant release processes depend on the type of waste management facility. For example, for below ground facilities, release mechanisms may include seepage (pore water expulsion), groundwater flow and diffusion processes. At in-pit disposal facilities, release of contaminants through surface water could also occur where closure has been achieved using a permanent water cover over the tailings. There is a wider range of release processes for surface impoundments because they usually extend over large areas and include a variety of critical control features such

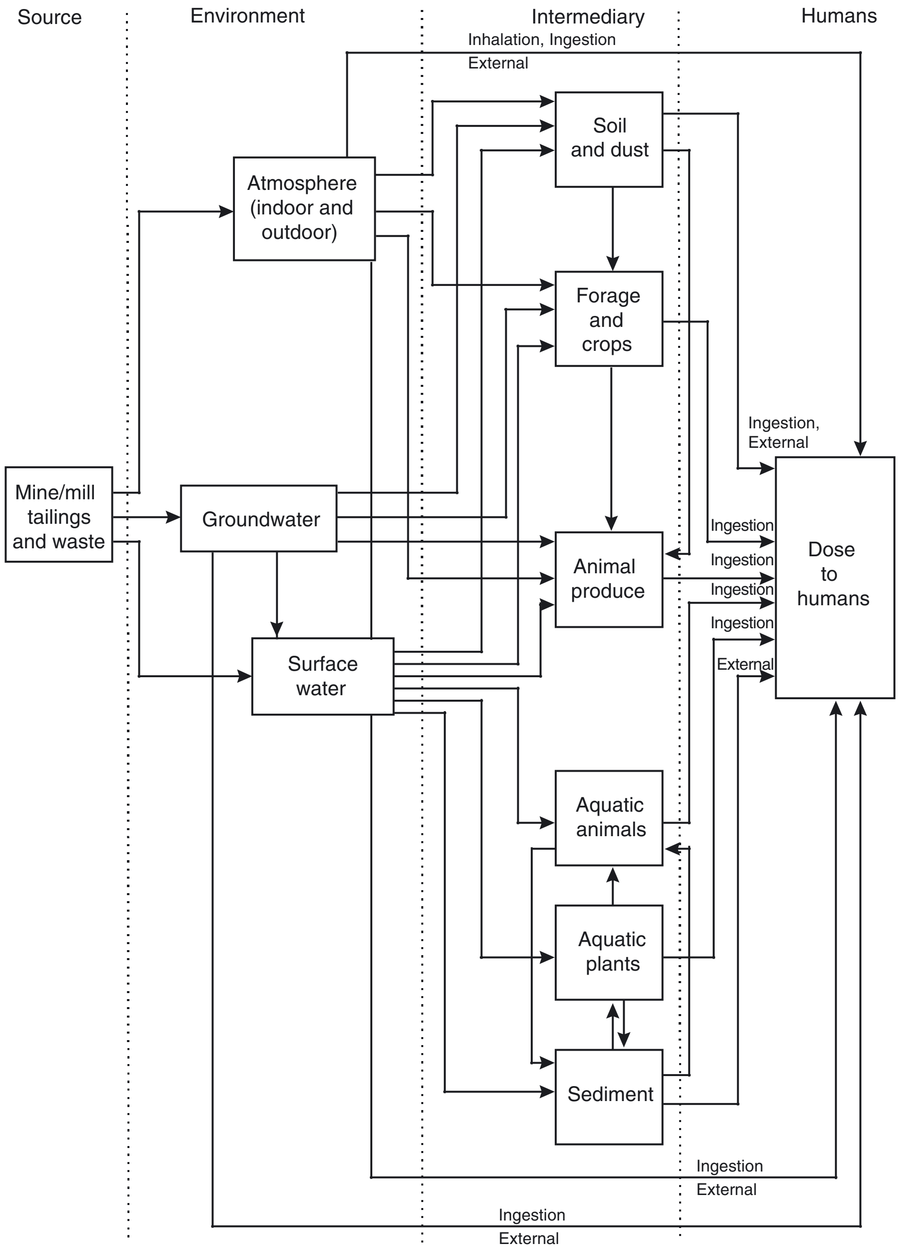

FIG. 4. Potential environmental transfer pathways to humans.

as embankments, liners, covers, water control structures (spillways, decant towers) and water treatment plants. These control features need active maintenance and surveillance to ensure their long term integrity and performance.

Releases are sometimes caused by the mass movement of the waste or the cover. Geotechnical instability, erosion, biological penetration or human intrusion in relation to the waste can lead to the transport of contaminants to the environment.

This section briefly describes the important release processes, the factors governing such releases, and the general environmental pathways by which the pollutants can reach humans and the environment, given a typical mill tailings site or mine waste pile as the source. This information is provided to assist in the development of monitoring and surveillance programmes.

2.1. WATER AND WIND EROSION

Many natural erosion processes can lead to the release of radioactive and non-radioactive contaminants to the environment. Principal among these are water and wind erosion, which typically most seriously affect above ground tailings impoundments and waste piles. Once a tailings pond or mine waste pile has been covered and stabilized, erosion tends to become less of a problem provided that the cover remains intact. Water and wind erosion are less likely to occur in below ground waste management facilities.

Surface water erosion is the most likely mechanism for the degradation of unstabilized and stabilized tailings and mine waste over the long term. Surface water bodies adjacent to impoundments can cause erosion by overflowing their banks or meandering into the impoundments. Overland flow caused by precipitation events can cause gullying, below ground channelling, and sheet and rill erosion. Runoff water that contacts waste may become contaminated.

2.2. GEOTECHNICAL INSTABILITIES

Failure of waste management facilities can result in the uncontrolled release of large quantities of waste material and contaminated water to the environment which, in turn, could result in loss of life and damage to property in downstream areas. Impoundment and pile failure can be triggered by extreme events such as earthquakes, floods and severe storms, or by slower surface and subsurface processes such as erosion, spillway blockage and geotechnical instability caused by settlement and slope failure.

Overtopping during severe storms is a potential mode of failure for waste retaining embankments. Overtopping occurs when the capacity of an impoundment is exceeded because of either insufficient freeboard or failure of water level control systems. The resultant erosion leads to breaching of the embankment.

Damage to the covers of waste management facilities can be caused by erosion, intrusion by plants and animals, freezing and/or thawing action, desiccation, slippage of saturated material (from long term precipitation events), blowing over of trees, and settlement of drainage layers and other elements. The destruction of the cover obstructs water runoff, reduces the cover's sealant function, changes the water balance and permits the entry of oxygen, all of which result in increases in the rate of release of contaminants.

2.3. CONTROLLED RELEASE OF CONTAMINATED WATER

For mill sites where there is low evaporation and/or high precipitation, the water balance may be such that a controlled release of contaminated water is unavoidable. This may entail discharge to the surface environment or injection into deep geological formations. There needs to be an established procedure for these releases, including stipulation of discharge criteria such as dilution limits, concentration limits and load limits for specific contaminants. However, wherever possible, discharge water is treated using current technologies [5–6] to reduce the concentrations of radioactive and non-radioactive pollutants. The volume of water that needs to be released can be minimized by recycling decant solutions and other process water to the mine or mill, and by proper site selection and engineering so as to control the inflow of fresh water to the mine or mill, as well as to the waste management facilities.

2.4. SPILLS DURING THE TRANSPORT OF TAILINGS OR MINE WASTE

During mill and mine operations, the tailings, mine overburden and waste rock are transported to an impoundment area in one of two forms, either as a slurry or as dry material. Slurried tailings are transported to the impoundment area through pipes that may be several kilometres in length. These pipes may fail or have joints and connections that may leak. Dry tailings or mine residues also contain small amounts of water and can be transported by truck, train or conveyor. If trucks or trains are used and the material is not properly covered, it can be released to the environment. Conventional conveyor systems also have a potential to lose material from the belts, especially at turns or belt interfaces. Stations where material is transferred from one mode of transport to another may also be important sources of contamination. Regardless of the means of transport, leaks and spills may cause contamination of surrounding areas.

2.5. UNAUTHORIZED REMOVAL OF TAILINGS AND MINE WASTE

Mill tailings appear much like sand, and mine waste may be composed of fine grained or crushed rock material. There have been cases where tailings have been used in the construction of buildings and roads. There is a concern that if this material were to be used to construct a building, the radon that would be released may be trapped in the building's structure. This would result in increased exposure of the occupants to radon emanation from the structure and to gamma radiation from the material. The waste material can also be removed or disturbed by burrowing animals, spreading contamination throughout the surrounding area. Removal of cover materials for other purposes also may expose waste.

2.6. CONSTRUCTION OF BUILDINGS ON TAILINGS AND MINE WASTE

It is not uncommon for residential dwellings or commercial facilities to be constructed on unremediated mine and mill sites, particularly in areas where there is a high demand for land. Occupants of such buildings would be exposed to direct radiation and incur exposure due to the inhalation of particulates, radon and radon progeny, as well as potentially incurring exposure due to direct ingestion of contaminated material. Construction projects on these sites may also compromise the structural integrity of the waste piles, leading to subsequent release of contaminants to the environment.

2.7. RADON EMISSION

Radon, a noble gas decay product of ^{238}U and ^{232}Th, is released from tailings and mine waste at all stages. Only a small fraction of the radon produced in a waste pile is released to the atmosphere [7], owing to the combined effect of the relatively short half-life of radon (3.8 days for ^{222}Rn; 55 seconds for ^{220}Rn) and the long diffusion path through the pile itself. Radon release is also affected by climatic factors such as wind speed, air temperature, relative humidity and soil moisture content. A cover over the waste inhibits release of radon to the surrounding air. However, if the cover is damaged, radon levels outside the waste management facility may increase.

2.8. DUST EMISSION

Tailings and mine waste are frequently made up of very fine particles that contain long lived alpha emitters, heavy metals and silicates. When disturbed by the wind, this fine particulate material is dispersed as dust to the environment. Dust emissions can be controlled by maintaining an adequate cover.

2.9. DIRECT GAMMA RADIATION

Although gamma radiation is not a contaminant in the usual sense, direct radiation originates from uranium and thorium mineralized materials and tailings. However, this is an issue only if such materials are exposed at or near the surface of the waste pile. The risk to environmental and public health arising from such sources is generally very low. A cover of barren waste rock 500 mm thick is generally sufficient to ensure that radiation is reduced to levels acceptable to regulatory authorities.

2.10. SEEPAGE

Another important release process from both above and below ground waste management facilities is seepage of contaminated water into surface water and groundwater. For above ground waste management or former heap leaching facilities, water within the waste derives primarily from the infiltration of precipitation and surface runoff, although infiltration of groundwater may be important in some situations. Water that was retained in tailings after processing can cause excess pore water pressure, which will expel contaminated water, especially by consolidation. In open pit waste facilities, seepage can be caused by the mechanisms mentioned above. In below ground facilities such as old mine workings or in situ leaching fields, seepage occurs mainly as a result of groundwater passing through the waste material, but excess pore water pressure can also be a factor. Waste management facilities that are left uncovered may be a source of continuous contaminant seepage.

2.11. DIFFUSION PROCESSES

In a properly designed below ground tailings facility, the tailings and mine waste are drained and consolidated before closure and a permeable envelope provided. As a result, there will be no excess pore water pressure to expel contaminants and groundwater will take the path of least resistance around the tailings. The predominant mechanism for loss of contaminants then becomes molecular diffusion, the rate of which is directly proportional to the concentration gradient.

3. INITIAL ENVIRONMENTAL SURVEYS

Prior to the implementation of a full monitoring and surveillance programme, it is necessary to determine the pre-existing status of the area [1]. Ideally, this is undertaken prior to operation of the mining and milling facility by conducting what is termed a baseline survey. However, for operating or abandoned facilities, a characterization survey may be required. Both of these initial environmental surveys provide the basic information necessary for future planning and the development of appropriate monitoring and surveillance programmes.

3.1. BASELINE SURVEYS

The results of radiological and hazardous material surveys performed after a uranium or thorium mining and/or milling site begins operations are always compared with environmental conditions prevailing at the site before operations began. In order to make this comparison, a baseline environmental survey for a new facility should be performed immediately after the site is selected so as to assess the site's existing environment [1].

The baseline survey includes measurements of air quality and general radiation levels, and provides details of groundwater and surface water chemistry. Samples of biota and soil also need to be analysed in the survey. In the selection of parameters to be included in the survey, account should be taken of site specific factors (e.g. the climate, the location of the site, the geological conditions, the design of the facilities, the off-site environment and the population distribution) [1]. Photographs allow the effects of mining and milling operations on the original landscape to be assessed.

The air quality survey may include measurements of gases and airborne particulates containing radioactive and chemical constituents at locations on, around and remote from the proposed operational site.

Water monitoring generally includes the characterization of groundwater and surface water flow and quality. A sufficient number of groundwater monitoring wells need to be installed to allow determination of the groundwater flow regime at the site and to assess up-gradient and down-gradient water quality. Where there is an established drainage path near the proposed site, surface water samples are generally taken at locations upstream and downstream of the site; alternatively, localized water bodies may be sampled.

A significant body of information on the gamma radiation levels and mineral distribution on the site may have been acquired prior to a proposal to develop a mine. The baseline survey supplements this information. A more comprehensive external radiation survey of the site and its environs may be obtained by conducting multiple traverses of the area of interest with portable low level radiation meters. Alternatively, aerial radiometric techniques may be used to gather data to produce contour maps as shown in Fig. 5. These measurements provide a reference for determining, at a later date, whether site operations have contaminated surrounding areas through wind and water pathways.

Soil is usually sampled to a depth of 15 cm, with gamma radiation measurements being taken at the same locations, both at the ground surface and at 1 m above the surface. The chosen sampling grid varies depending on site conditions. Four transects at 90^{o} are often established, one in the predominant wind direction. The spacing of the sampling sites is close (a few tens of metres) near the proposed operations and greater (up to 5 km) at the site boundaries and beyond. A smaller grid (30 m) may be necessary on proposed ore and waste storage sites, processing sites and ore transport routes. Proposed living areas may also be sampled on the smaller grid to provide the necessary degree of confidence for potential radiation dose assessments.

In assessing the ore body, it is normal to examine the equilibrium in the ^{238}U chain, the presence of the ^{232}Th chain, and the presence of other significant elements, such as vanadium, arsenic and nickel, as well as important minerals such as carbonates and sulphides. The baseline survey includes a full assessment of all metals in a few samples but focuses on the significant radionuclides and stable elements identified from the ore body assessment. Normally, the following elements and radionuclides are analysed: total U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{232}Th and ^{228}Ra, as well as any significant stable elements identified in the full metal scan and the ore body assessment, such as vanadium, arsenic, nickel, selenium and molybdenum. In evaluating the radiological hazards of mining and milling waste, account must also be taken of non-radioactive hazardous materials which may be present. Some of these may be of greater environmental concern than the radioactivity of the waste or give a more rapid indication of environmental pollution.

3.2. CHARACTERIZATION SURVEYS

For existing facilities, pre-operational environmental data are often unavailable. Analysing information from background locations (unaffected by past or current facility operations) and information about the existing nature and extent of contamination provided by the characterization survey will aid the understanding of the pre-operational environmental conditions and the identification of changes produced by prior operations and waste management practices. However, it is important that the area being used to establish background conditions be environmentally similar to the site, as environmental conditions can change over short distances.

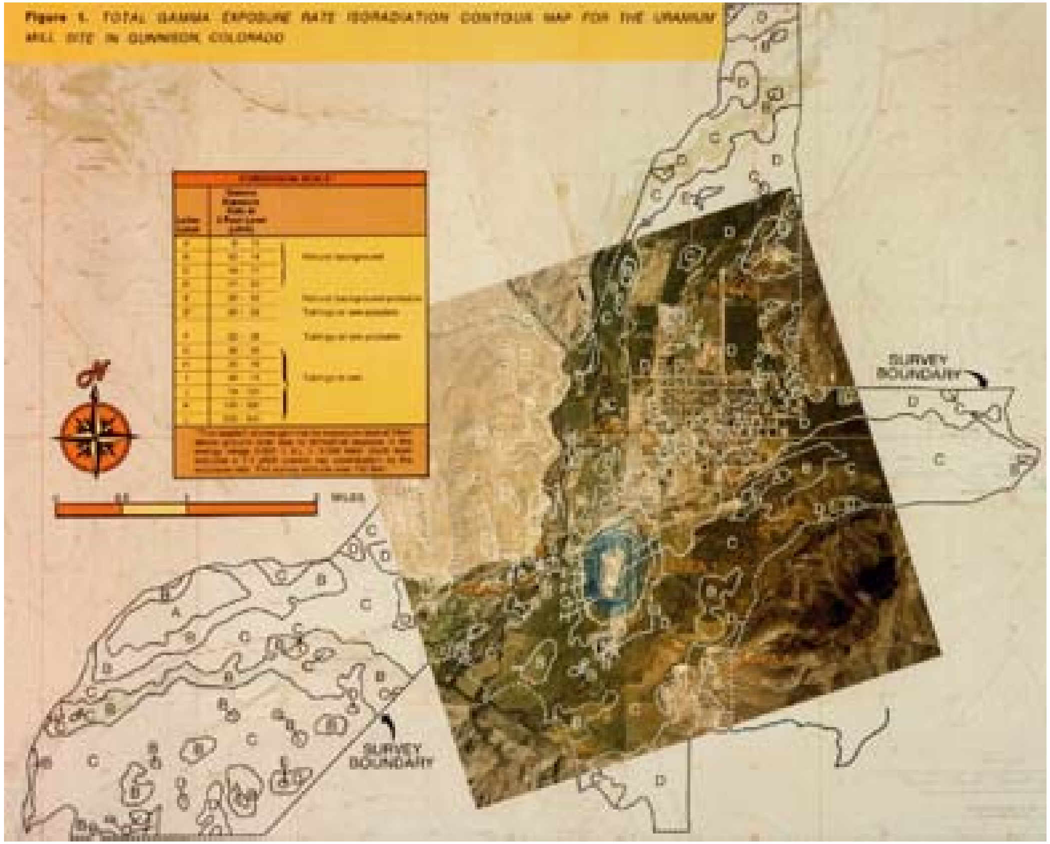

FIG. 5. Aerial radiometric survey contour map.

Characterization and baseline surveys use the same measurement and sample analysis techniques as those applied to the environmental media. However, for characterization surveys, soil sampling may be conducted at greater depths to assess contaminant leaching into subsoil, sampling of waste materials is necessary, and the use of a non-uniform distribution of monitoring wells may be needed on the site, as well as off the site, to track possible existing contaminant groundwater plumes. An IAEA publication provides additional information on performing site characterizations [8].

4. MONITORING PROGRAMME

For an operational mining and milling facility, a monitoring and surveillance programme is part of the overall management process. The monitoring programme should be based on the results of a baseline or characterization survey and be revised throughout the life of the project to take account of changes in operations and technology, as appropriate. The owner/operator should establish monitoring and surveillance programmes to obtain the data necessary to demonstrate to the regulatory authorities that environmental, radiological or chemical contamination is not exceeding regulatory standards and that possible releases from a tailings pile or mining waste are not likely to cause unacceptable radiological or chemical exposure to the environment or to human health [1].

In general, the type of information collected during operations and after the site is closed is the same as that collected in the baseline survey. However, additional or different information may be required after site closure because the residues will reside in a chemically or physically modified form owing to the mining, milling or in situ leaching processes.

Monitoring in the environment of mill tailings and mine waste includes water quality monitoring (such as concentrations of contaminants), atmospheric monitoring and other biosphere monitoring such as soil, fauna and flora, especially those components involved in the food chain. The location and frequency of the monitoring are based on the stage in the life of the facility, the proximity of the general population and the risk or potential risk to the critical group. Environmental media sampling is normally more intense during facility operations, to accommodate changes in waste volumes and waste types being generated, and less frequent during the post-closure period, when changes are driven by slower, natural processes. The monitoring programme for a particular site depends on many site specific factors such as climate, design and location of the facility and tailings system, storage volumes and mineralogy of the ore and waste rock, process chemistry, population distribution and regulatory requirements. The design of a programme, including environmental media to be sampled, sample locations and sampling methods, is based on a site specific safety assessment and risk analysis, the results of which assist in identifying:

(a) Critical radionuclides and chemical contaminants;
(b) Important pathways that may contribute to radiological or chemical exposure of critical groups and releases of contaminants to the environment;
(c) Critical components of the tailings or mine waste management systems, failure of which could result in significant releases of contaminants to the environment.

Monitoring and surveillance programmes need periodic review, revision and modification to accommodate changes in waste management practices, environmental conditions, regulations and potential receptor locations that may occur throughout the life of the facility.

4.1. PATHWAY ANALYSIS

The development of the monitoring and surveillance programme is based, in part, upon the results of an analysis of radionuclide transfer pathways to humans, using the proposed waste management plan for new facilities or the actual site conditions for existing facilities. In this way, impacts on humans may be estimated and appropriate monitoring locations and measurement requirements identified. These analyses are modified and refined as facility operations change and as environmental data from the implemented monitoring programme are acquired.

The release of contaminants, their environmental transport and their exposure pathways are conceptually depicted in Fig. 5, and the various release mechanisms discussed in Section 2. The pathways by which humans may be exposed to radiation may be generalized as follows:

(a) Atmospheric pathways that can give rise to doses due to inhalation of radon and its progeny and airborne radioactive particles;
(b) Atmospheric and terrestrial pathways that can give rise to doses resulting from external radiation and ingestion of contaminated soil and foodstuffs;
(c) Aquatic pathways that can give rise to doses from the ingestion of contaminated water, foods produced using contaminated irrigation water, fish and other aquatic biota, and foods derived from animals drinking contaminated water, and from external radiation.

In addition to this, a pathway analysis for non-radioactive hazardous material should be performed simultaneously to assess the associated environmental impacts and monitoring requirements.

The exposure pathways are highly site specific and time dependent. For example, at arid sites contaminated dust particles and radon gas are major contributors to the estimated radiation dose to the critical group via airborne dispersion followed by inhalation, whereas the water pathway usually contributes an insignificant component. However, at sites where annual precipitation is high enough to result in permanent surface water systems, the pathways for contaminant transport by surface water and groundwater can be the dominant exposure routes. Exposure to airborne contaminants is reduced because tailings or mine waste with high moisture contents are less likely to cause doses due to dust and radon, and these sites generally support vegetation, which also inhibits the release of contaminants to the atmosphere. Infiltration of water at these sites is likely to increase contaminant leaching and seepage from the waste facility, depending on the chemical composition of the waste and host material and on the permeability of the percolated bodies.

During the post-closure period, the potential exposure pathways are likely to be associated with radon emission and the seepage of contaminated liquids. In the medium to long term post-closure periods (for example, greater than 100 years), scenarios that include the following factors may be of importance:

(i) Human activities (e.g. activities that disrupt the integrity of the pile cover or which result in entry into the repository, such as construction and drilling for mineral resources and water);
(ii) Natural processes and events (e.g. erosion, changes in surface water courses and seismic events);
(iii) Internal tailings processes (e.g. failure of structural impoundment, differential settling and cover cracking, and initiation of pyrite oxidation).

Predictive analysis of radionuclide transport to humans can help determine the focus of monitoring and surveillance programmes at each stage of the facility's life. Numerical computer models are available or may be developed for the site to simulate the environmental transfer of radionuclides and the resulting radiation dose to humans due to the various waste sources.

This type of analysis is commonly used, for example, in the design of disposal facilities for low level radioactive waste [9–10] and for the disposal of high level radioactive waste. Site specific parameters needed to perform the analyses are obtained as part of the initial site baseline or characterization survey (Section 3).

4.2. MONITORED MEDIA

The basic parameters monitored (e.g. constituent concentrations) are normally the same for all phases of the facility's (mining, milling and waste management) life. However, sample locations, frequencies and analytical methods may change to reflect changes in waste management activities performed in the mining and milling operations and improvements in technology. Therefore, the monitoring programme needs to be reviewed periodically to maintain an appropriate level of monitoring. The programme review should consider the initial baseline environmental conditions established for the facility (baseline and/or characterization survey results), previous monitoring results, current operations and the estimated potential risks to critical groups. The review should assess the evolution of environmental conditions and provide opportunities for invoking timely remedial actions to mitigate the consequences of any adverse impacts. The programme also needs to include the monitoring of radioactive discharges from operating facilities [2, 10]. General monitoring requirements for the environmental media are described in the following sections.

4.2.1. Water monitoring

Water monitoring is performed to determine the potential for short and long term contamination due to migration of contaminants from the waste management facility and its environs (see Fig. 6). Parameters monitored may include the quantities and rates of flow, infiltration, percolation and seepage, as well as the concentrations of radioactive and chemical contaminants in surface water, groundwater and tailings or mine waste pore water. The contaminants that should be measured depend on the site specific factors, including the geochemical characteristics of the wastes, host rocks and underlying soils, and the process chemistry used at the facility. Typical radionuclide constituents to be measured include total U, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{232}Th, ^{210}Pb and ^{210}Po. The gross alpha activity of water samples is also determined. Non-radiological metals such as Se, V, Mn, Fe, As, Ba, Cd, Cr, Ni and Cu are commonly measured, as well as major ions such as carbonate, ammonium, sulphate, chloride and nitrate. This monitoring can provide useful data on the potential for radionuclide migration as well as other non-radiological environmental impacts.

In tailings, heap leach and mine waste piles, as well as within in situ leaching residues, chemical reactions may occur that could cause changes in the availability of contaminants. The best known example is acid rock drainage. In such cases, the oxidation of sulphidic compounds present in a waste material increases the acidity within the waste. This could mobilize acid soluble contaminants, in particular heavy metals. If the water resources become contaminated on a site where acid rock drainage is found, remedial action is taken and monitoring used to determine when acceptable contaminant concentrations have been achieved and to provide evidence that any remedial actions undertaken have been successful. Monitoring needs to be continued to provide assurance of the sustainability of the remedial action.

4.2.1.1. Surface water

Surface water may be used for a range of beneficial uses, including recreation, drinking, irrigation of crops and watering of livestock, all of which are major pathways for human exposure. Monitoring is directed towards surface waters that pass near or through waste piles that could be subject to seepage or that could be affected by failure of impoundment structures. Measurement and sampling locations are selected on the basis of an assessment of local hydrological conditions and the location of the waste management facility. Samples should be taken both upstream (to provide background information) and downstream of potential sources of contaminants. The maximum distance from the tailings and other disposal areas at which the surface waters are sampled depends on downstream water usage and on the likelihood of the surface water bodies receiving contaminants either from erosion of the waste source or through the discharge of contaminated groundwater into the surface water body.

FIG. 6. Water sampling.

Surface water is collected by an approved method, for example, by collecting water directly in clean sampling containers or by use of a small peristaltic pump. The water is usually passed through a filter directly into a sample container. Peristaltic pumping is preferred because water contacts only the inert pump tubing and cross-contamination can be avoided by replacing the pump tubing. Liquid samples are usually analysed for turbidity, pH, Eh, alkalinity, specific conductivity, dissolved oxygen, nitrate, and the trace elements and radionuclides listed in Section 4.2.1, as appropriate to each sample point and as set out in the site specific monitoring programme. Any material collected on the filter paper is analysed for the same range of trace elements and radionuclides.

4.2.1.2. Groundwater

Groundwater monitoring is essential for both operating and closed facilities having mining waste. The probability of groundwater contamination occuring is highest during the facility's operational phase. For example, at mill sites, wet slurries containing leached ore are continually being added to the tailings piles, which produce an elevated hydraulic head on the tailings material and enhances seepage into groundwater. Groundwater monitoring is of particular significance at sites concerned with the in situ leaching of uranium and thorium minerals. In general, mechanisms for the transport of pollutants to the groundwater are: percolation of precipitation, tailings slurry water or heap leach solutions through the pile; expulsion of residual pore water remaining in the tailings; or ascent of groundwater into the pile. However, when these piles are stabilized and covered, infiltration rates and groundwater recharge rates are greatly decreased, which reduces the seepage of contaminants from the facilities and, thus, reduces groundwater contamination.

This may not be the case for tailings that are placed back into mine excavations. When dewatering of the mine is stopped at the end of operations, groundwater flows through the mined area increase and, unless preventive measures are taken, flow through the waste may also increase. At terminated in situ leaching operations, uncontrolled groundwater will continue to move through the previously leached ore body and may continue to leach contaminants from it.

Groundwater movements may be very slow and geochemical reactions may retard the movement of contaminants relative to the groundwater flow. Consequently, the contaminants may take decades to migrate to a monitoring, drinking or irrigation well, and may not be detected until after the site is closed.

The groundwater monitoring system should comprise an appropriate number of wells to yield sufficient samples or measurements and thereby enable monitoring of:

(a) Groundwater that may be affected by seepage from the operating or closed facility;

(b) Groundwater that leaves the owner's area of responsibility;
(c) Groundwater that enters into the owner's area of responsibility (changing background due to external sources);
(d) Water that reaches locations where it might be used for drinking, agricultural or other beneficial purposes;
(e) The level of piezometric surface(s) (various aquifers).

The network of monitoring wells is designed, using the results of pathway analysis, to enable measurement of groundwater contamination at as many locations as necessary to adequately describe the groundwater characteristics. Monitoring wells are placed upstream, within and downstream of the contaminant sources. The same locations should be used for measuring contaminants during operations as well as after closure. The data collected during operation of the facility can be used to identify trends in the concentrations of contaminants after closure, using pathway analysis modelling.

Upstream monitoring wells are used to determine the background concentrations of the contaminants being monitored. If there is more than one surface drainage flow through the area of concern, then monitoring wells are usually placed in each drainage area. Upstream wells should be positioned such that the water quality is representative of the groundwater entering the operational area. Upstream wells are placed as close to the contaminant source as the site development plan will allow but far enough away to ensure that water is not affected in any way by the operation. The siting of wells should take into account the hydraulic properties of the soil and underlying rocks. It is necessary to make numerous measurements over time to determine the natural variations in background concentrations. This is because groundwater that is upstream from the contaminated sources could take years to reach the wells in the operational area.

Monitoring wells are located within and at the downstream boundaries of the waste disposal area so as to provide information on the concentrations of contaminants present in the groundwater beneath the source. This information is needed to determine the relative concentrations of individual contaminants. If the groundwater at downstream wells is similar to that at wells near to the operational area, the concentrations would not be expected to decline at these wells in the near future. Care has to be taken to ensure that the monitoring wells within the source do not act as a conduit that allows surface water or precipitation to migrate through the source.

The majority of wells in the monitoring system are normally located downstream of the tailings or waste pile. These wells provide the information needed to determine the approximate geometry of any contaminated zones and the potential for the advancement of the contaminated zone towards existing or potential water resources. Several of the downstream wells need to be placed at the property boundaries to determine whether the site is in compliance with regulatory requirements. Other wells are aligned to the probable direction of contaminant movement near the boundary of the contaminated zone in order to provide information on the rate of movement of the contamination plume.

Monitoring wells are typically encased in a manner that maintains the integrity of the monitoring borehole. This casing is screened or perforated and packed with gravel or sand, where necessary, to enable the collection of groundwater samples from appropriate horizons. The space between the borehole and the well casing, at the surface, is sealed to prevent contamination of samples and groundwater from direct infiltration of surface runoff. Particular care must be taken to ensure that monitoring wells do not connect vertically separated aquifers. The layout of the monitoring well system has to take account of the hydrogeological situation. For instance, near to potential contaminant sources (less than 100 metres), shallow groundwater monitoring bores can be used to detect near surface seepage. These shallow bores do not penetrate to deeper aquifers but can provide early response to near surface effects.

An example of a simple programme of groundwater monitoring is illustrated in Fig. 7 and shows the need to consider both the location of the wells and the aquifer depth being sampled.

The methods, analytical procedures and contaminant used for groundwater monitoring are similar to those used for surface water monitoring (see Section 4.2.1).

4.2.1.3. Pore water

Pore water is resident in the pores of the waste mass and usually moves very slowly. Results from monitoring of pore water quality can be useful in helping gain an understanding of what geochemical changes are taking place within the waste mass. This information may also be used to chart or model the release and migration of radionuclides and other contaminants from the tailings or mine waste. In saturated waste, below the water table, pore water may be sampled using wells that extend into the pile, but which do not pass through the base of the pile. Samples can be taken and analysed using the same methods as those used for groundwater. In unsaturated tailings or waste piles, pore water cannot usually be sampled using wells; this requires the use of specialized techniques, for example, the use of suction plate apparatus or the compression of core samples of waste material to extract the moisture. Alternatively, lysimeters (buried water collection vessels) may be installed in the waste facilities and sampled periodically.

4.2.1.4. Percolation water

The release of contaminants and chemical loads caused by infiltration water and by percolation of the cover and waste depends on the efficiency of the cover and the established vegetation. To estimate these releases, a water balance of the waste management facility needs to be determined.

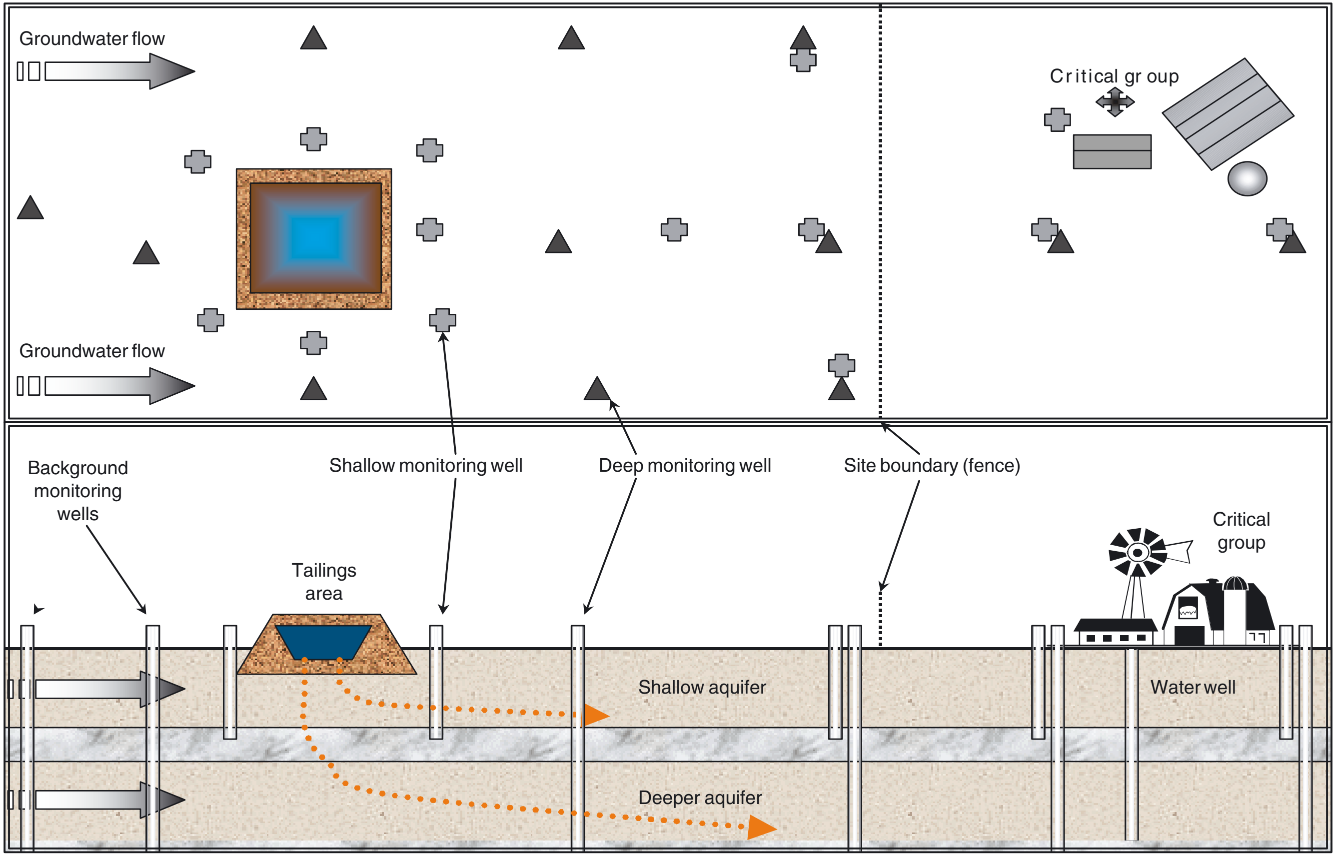

FIG. 7. Example of groundwater monitoring locations for a tailings area.

Data needed for the water balance include details of temperature, precipitation, relative humidity, wind speed, evaporation rate and surface runoff. Lysimeters that measure the quantities of infiltrating water percolating through the covers are installed in the revegetated cover, in the drainage layer or under the sealant layer of the cover. The upward and downward movement, the capillary tension and the field capacity of the cover materials are measured by tensiometers and vacuum lysimeters. The quantity and concentrations of waste seepage are measured at sampling points at the drainage system outlets or at the toe of the pond or pile. Sampling methods are similar to those used for surface waters, although samples may also be obtained from horizontal borings into the waste. Estimates of the extent and rates of infiltration and percolation can be made by combining information based on all available data, but some uncertainty will still remain. However, the water balance can provide the information necessary to take a decision regarding the efficiency of the cover and the need for repairs.

4.2.2. Atmospheric monitoring

Atmospheric monitoring programmes generally focus on two parameters: airborne particulates and radon. To establish a programme for measuring concentrations of airborne particulates and ambient radon, site specific meteorological data are collected during initial environmental surveys as noted in Section 3. The sampling locations are determined during the baseline survey phase, if possible, or at the site characterization stage, and modified as necessary during the operational and closure phases. The sampling locations are selected with the annual frequencies of wind speeds and directions taken into account. Other meteorological factors such as barometric pressure, atmospheric stability, rainfall and temperature may also assist in determining air sampling locations and frequency. The sampling locations normally surround the site and a significant number of points are clustered along the dominant annual or seasonal wind directions, downwind of the site. Atmospheric dispersion modelling may be useful in selecting monitoring locations during each phase of the facility’s life.

4.2.2.1. Airborne particulate matter

Particulate matter can become airborne at a tailings impoundment or mine waste pile through the action of wind or machinery such as trucks and conveyors. Although the main concern is radioactive particles, which could be an important source of inhaled radioactive material, airborne trace metals also need to be considered. Most of the radioactive particles contain members of the ^{238}U decay series but, where ^{232}Th is present in significant quantities, members of its decay series also need to be considered.

A sufficient number of background sampling locations are established around the waste facility to ensure that upwind samples can be obtained independently of seasonal variations in wind direction and other parameters. These sampling locations may also change as the waste management facility develops. The size and shape of the waste management facility may cause changes in local wind currents and associated atmospheric dispersion.

Samples from locations downwind of the source indicate the types of contaminant being suspended as a result of wind erosion. These sample locations are based on the predominant wind directions for the area. Air samplers are normally located immediately downwind of the facility, at the boundary of the licensed property, and further downwind near areas where there may be general public access. The boundary monitors provide data that can be used to determine regulatory compliance. A pathway analysis can assist in the selection of monitoring locations during the life of the facility.

Samples are collected using portable or fixed air sampling systems. These systems normally consist of a pump drawing air through a filter that collects the airborne particulates and a flow totalizer to record the volume of air passing through the collection filter during the sampling period. Grab samples collected over a few minutes are particularly useful for monitoring rapidly changing concentrations or obtaining multiple samples from several locations quickly. Long term, integrated samples are taken over periods of up to several weeks, using high volume samplers where concentrations are low. Both options need to be considered when setting up the monitoring programme. Permanent sampling stations are protected from the weather, but must still allow representative samples to be collected.

For the purposes of estimating radiation doses from radioactive contaminants, the respirable particle size is determined using a cascade impacter or similar system. This particle size sampling need not be performed at every sampling location every time a sample is taken. Representative samples are taken and characterized whenever major changes occur to the pile configuration, to mill activities or to the tailings or waste placement process. This characterization is normally checked annually. Alternatively, a conservative approach to particle sizing may be taken by using a worst case particle size. This may overestimate the potential dose but can reduce the monitoring requirements.

The airborne particulate samples are analysed to determine the radioactive constituents and detect any heavy metals or mineral fibres. The typical radiological analysis is for natural U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po. However, if ^{232}Th forms a significant fraction of the ore content, then the analysis also covers ^{228}Th, ^{232}Th and ^{228}Ra.

4.2.2.2. *Radon gas*

A monitoring programme for radon gas usually involves the sampling of ambient air concentrations at the same locations as those where particulate sampling is performed. Ambient radon measurements can be used to quantify the health risk to critical receptors due to radon progeny. It should be noted that post-closure radon releases may increase if there are disruptions to the waste management facility's cover. Inspection of the cover is an important element of the surveillance activities.

Ambient radon can be measured by grab sampling or by passive monitoring that measures the average ambient concentrations over several weeks or a month. Active monitoring instrumentation can be used to measure short lived alpha emitting radon progeny directly.

Radon exhalation data from bare surfaces of the waste management facility may be needed as input for a risk assessment through pathway modelling and to assess the need for remedial action and the type of remedial action necessary to minimize the radon release from the site in the long term. Exhalation data from the pre-operational and operational phases can provide the basis for evaluating the effectiveness of reclamation techniques used during closure.

The exhalation rate can be measured by inverting a cylindrical container with one open end on the surface and measuring the increase in the concentration of radon inside it. A network of exhalation sampling points provides data representative of the surface.

Moisture content and temperature of the waste material are important considerations in radon exhalation. Wherever possible, information on the variability of radon exhalation rates with respect to differing weather conditions and seasons needs to be included in the programme.

4.2.2.3. *Example of atmospheric monitoring programme*

An example of a basic monitoring programme for the atmospheric transport pathway is given the Fig. 8. The monitoring is designed to investigate the emissions from the operation, the natural background environmental levels and the impact on critical groups. For the principal sites, more advanced monitoring methods are used such as electronic radon decay product monitors and high volume dust samplers. For other areas, simple and inexpensive dust deposition gauges can provide environmental information at lower cost. In addition, soil, vegetation and gamma dose rate sampling may also be undertaken to detect any long term change in environmental levels due to atmospheric transport and subsequent deposition of particulate material. By using information from remote sites, the natural background component may be identified and removed to allow determination of the impact of operations on the critical group.

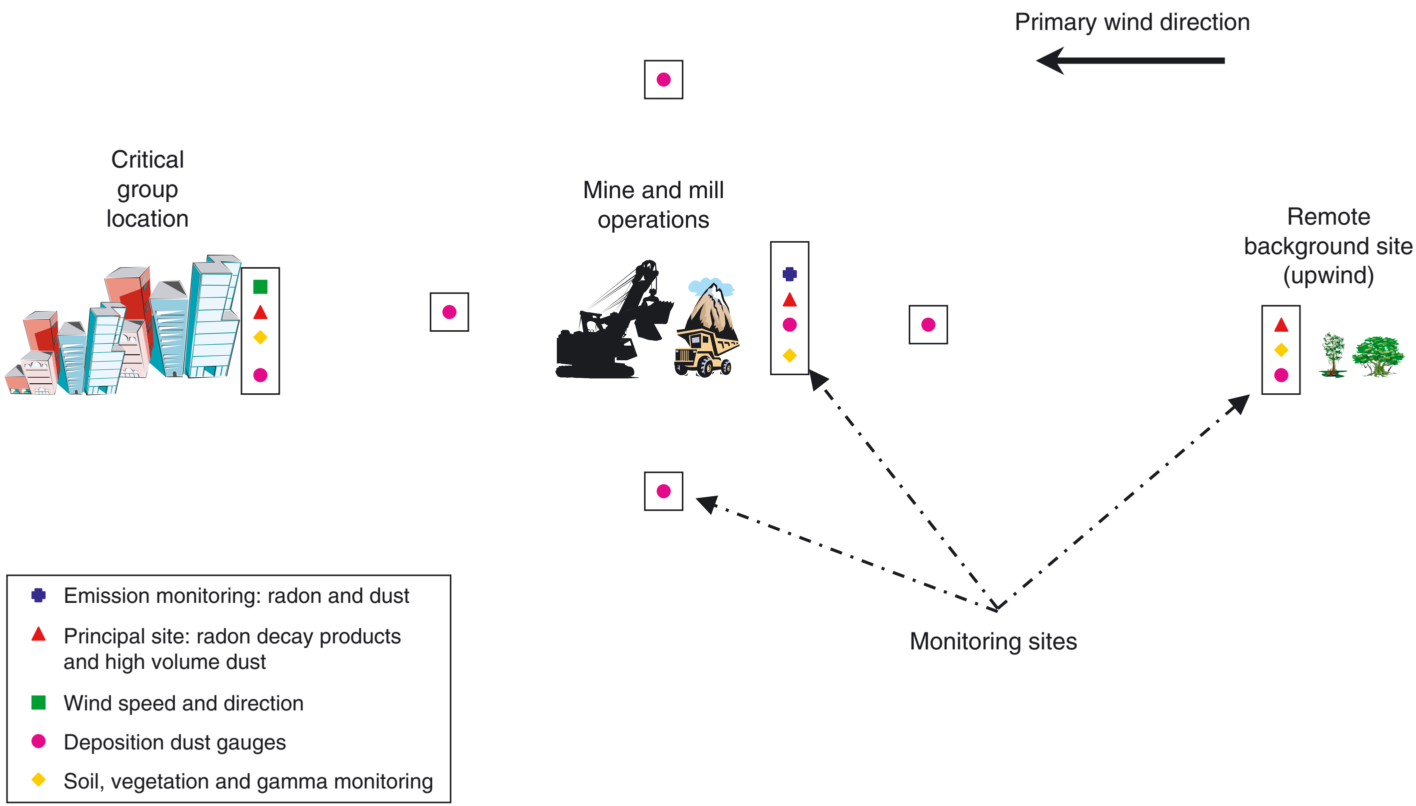

FIG. 8. A basic monitoring programme for the atmospheric transport pathways.

4.2.3. Gamma radiation levels

A record of the gamma radiation levels of the tailings and mine waste piles and the surrounding area is necessary in order to use increases in the radiation levels to detect any spread of radioactive material that may occur. The initial readings taken during the baseline or characterization survey will be used as the basis for purposes of comparison. It is recognized that as tailings or mine waste is placed in the facilities, the general radiation levels of the area will increase. Away from the piles, the radiation levels ought to be close to the background levels for the site. Any increase in these levels may be an indication that material is being dispersed outside the controlled areas.

Surveys are typically performed using a low level environmental monitoring meter or a sodium iodide detector calibrated against a pressurized ionization chamber. Survey points need to be established and permanently marked so that they can be monitored on a routine basis. These points may be located around the tailings or mine waste piles and further away, outside the influence of these sources. This can be accomplished by locating these points on a regular survey grid or along radials from the piles. Radial measurements in the eight compass directions provide adequate coverage. The distance between measurement points along the radial could increase with distance from the piles. Survey points may also be chosen on the basis of a site's importance, such as active working areas, residential sites or sites of special environmental or cultural significance. Alternatively, periodic aerial radiological surveys may be made (see Fig. 5). An integrated record of external radiation levels over several months may also be obtained using strategically located environmental thermoluminescent dosimeters.

There may be other sources in the area that could affect the gamma survey, including milling and mining operations, tailings impoundments, mine waste piles, transport routes for ore and mine waste, other practices, and naturally occurring sources.

The gamma survey can also be used to determine whether the effectiveness of any cover over a waste or tailings facility is being reduced by one or more of the erosion or other mechanisms discussed in Section 2. In areas where erosion or other destructive mechanisms may be factors (animal burrowing, human exacavation), gamma surveys are performed. These results are recorded on a map with the survey locations, which will have been identified by markers on the tailings or waste facility. Appropriate remedial actions are taken and gamma radiation levels measured around the area of concern until background levels or normal levels are observed, as determined by comparison with baseline or characterization survey data.

4.2.4. Food, drinking water and soil monitoring

Monitoring is performed to determine whether levels of radionuclides (and other indicators or contaminants of concern such as heavy metals) in the environment are increasing, especially in the human food chain. Samples of meat and milk from the area which might provide food sources for humans are collected. Sampling is normally extended to include organisms that have been identified as being sensitive indicators of the ecosystem's health. Sampling of plants should not be limited to on-site areas; plants from downwind and downstream locations and from areas that use potentially contaminated water for irrigation are also included in the monitoring programme.

Discharge limits and environmental standards [11] are generally set to provide for the protection of humans. The baseline or characterization survey identifies the biota of importance according to their use as food or as sensitive indicators of eco-system changes or for other reasons such as cultural significance. These species vary from site to site. Drinking water which may be impacted by the operation is sampled, typically, twice a year depending on the local seasonal conditions. Soil and sediment are likely to show changes more slowly and are sampled annually until some experience is gained. If no problems are noted in relation to soil and sediment, then selected biota would be sampled approximately every three years. However, unusual events or major releases may trigger early and more frequent sampling of biota. Once the site is closed, the sampling frequency may be reduced.

5. SURVEILLANCE PROGRAMME

5.1. INTRODUCTION

The purpose of the surveillance programme is the prompt identification of conditions that may lead to a migration or release of radioactive and other contaminants from waste management facilities to the environment [1]. The surveillance programme is usually implemented through regular inspections of the critical components of the waste management systems. Visual inspections are usually the most effective way of detecting anomalies indicative of potential failures.

A site specific surveillance plan and implementation procedures should be developed early in the project's life. The plan should be periodically updated by the mine and/or mill operator, in consultation with the regulatory authority, to take into account changes in conditions at the site, in operations and in technology. The plan is revised prior to the stabilization and remediation of tailings and other waste.

The plan shows how the surveillance results complement the monitoring programme and site safety and performance requirements. Key elements to be included in the surveillance plan are:

(a) Description of the site and adjacent area,
(b) Description of components of the waste management system and environmental setting,
(c) Type and frequency of inspections,
(d) Inspection procedures,
(e) Contingency or maintenance actions,
(f) Reporting requirements for inspections,
(g) Quality assurance and record keeping.

An example of a long term surveillance plan (post-closure period) for a uranium mill tailings site is given in Annex I.

5.2. TYPE AND FREQUENCY OF INSPECTIONS

The frequency and the level of vigilance of the inspections are based on the site specific conditions and the potential risk to humans and on other socioeconomic, environmental and regulatory impacts associated with the failure of the waste management facility. A typical surveillance programme will include routine inspections, detailed inspections and special purpose inspections. Depending on the operational status of the facility, the responsibility for such inspections lies with the operator, the regulator or some other appointed representative.

5.2.1. Routine inspections

This type of inspection is undertaken on a regular basis by trained personnel and consists of a tour of the entire facility to ensure that the general condition of all the components of the waste management system is satisfactory. For example, in the case of embankments, the inspection visually assesses the general condition of the crests, abutments, slopes and associated water level control structures.

For all operating facilities, these inspections are typically undertaken daily or weekly, depending on the type and the number of control structures. A member of the operator's technical staff with adequate knowledge of the site usually performs the inspections.

For waste management facilities at the surface that have undergone closure, the routine inspections are usually carried out monthly or at least annually by the organization responsible for the long term management of the site. For closed, in-pit waste management facilities, the frequency of routine inspections may be reduced.

5.2.2. Detailed inspections

The purpose of a detailed inspection is to ensure that the waste management system is performing in accordance with the design criteria and complying with regulatory requirements. It is performed by a qualified person possessing a thorough knowledge of the site and the operational requirements of the waste management facility.

The inspection is preceded by a review of the previous inspection report, looking particularly for any items needing follow-up from the previous inspection, and a review of any monitoring and surveillance data produced since the previous inspection report. The inspections are conducted by walking around the site and include detailed examination of the condition of all the structures and reading of a random selection of site surveillance instrumentation. After the visual inspection, any findings are followed up by a detailed examination of all relevant data from surveillance instrumentation (piezometric levels, settlement plate readings) and relevant chemical parameters from the monitoring programme. The results of the inspection together with the updated surveillance data are presented in a formal technical report which includes the main findings and any recommendations.

For all operating facilities, detailed inspections are performed at least once a year. However, for major water or waste retaining structures it may be necessary to perform such inspections more frequently. In the case of above ground facilities that have undergone closure, the annual inspection programme is maintained by the organization responsible for the long term management of the facility. For all other types of waste management facility, the frequency of detailed inspections is determined on a site specific basis.

5.2.3. Special purpose inspections

Special inspections are conducted after extreme natural events such as fires, earthquakes, floods, severe storms, heavy rainfall or cyclones. The purpose of these is to ensure that the components of the waste management system have not been damaged but continue to be fully functional. Such inspections are carried out by trained personnel who can determine whether specialized technical assistance is necessary. The on-site procedure for performing special inspections is similar to that used for routine inspections but with special emphasis on critical components.

Special inspections are also performed at regular intervals throughout the construction of a new facility and during any major modification to an existing waste management facility, as well as during the remediation stage. This is to ensure that the construction or modification is performed according to the approved plans for the design.

5.3. INSPECTION PROCEDURES

Inspections have to be planned in consultation with the site staff to ensure safe access to all the necessary elements of the waste management system. Prior to the inspection, all the relevant information about the site and its components such as site plans, aerial photographs and reports on previous inspections need to be gathered and reviewed. The inspector assembles the relevant checklists and accessories necessary to perform the inspection (camera, notebook, tape measure).

During an inspection, the inspectors observe the condition of all permanent features, anomalies and unexpected features that may need closer inspection (erosion features such as gullies or rills, sediment accumulations, signs of vandalism or intrusion by animals, plant growth).

It is convenient to perform inspections by using checklists of the elements to be inspected. Such checklists are compiled specific to the type of inspection and the site in question. The use of checklists reduces the risk of essential elements being forgotten and improves consistency in the results of inspections performed by different inspectors. A typical example of a checklist is given in Annex II.

A photographic record of the site needs to be initiated during the pre-operational phase when the baseline survey is performed or during the characterization survey for existing facilities. Photographs are then taken periodically during the phases of construction and operation of the facility and during the closure and post-closure phases. This photographic record will indicate the condition of the waste management facilities, since recorded notes and memory are not always adequate in identifying gradual changes at the site reliably (see Annex III for a typical example of a photographic log that can be used during surveillance).

The exact locations of the subjects of the photographs are recorded, as is an indication of the relative location of the photographer, a brief description of the photograph and the reason why it was taken. Subsequent photographs are taken from the same position to allow comparisons to be made. Markers may be used to identify these locations to aid subsequent photography. Additional photographs (Fig. 9) are taken of any area of the site that has changed significantly since the last inspection. Any areas of concern are photographed to allow comparison with subsequent photographs and thereby determine whether conditions are deteriorating. Aerial photographic techniques may also be used.

Every inspection is completed with a written report. This may vary from simply annotated checklists from routine inspections to comprehensive technical reports after detailed inspections. The details of all maintenance modifications or subsequent modifications are also documented.

It must be emphasized that the actual inspection needs are determined by site specific conditions and the stage in the site's life. For example, disposal of uranium mill tailings and/or mine waste and mineralized waste in underground mines, open pits, ponds or lakes will entail different surveillance needs. For operating in-pit facilities, the major issues for surveillance are the stability of the pit walls, the efficiency of any installed under-drainage system and the adequacy of control systems for water management. Closed in-pit facilities will need surveillance of the cover to monitor integrity and management of any residual water body. Waste facilities in underground mines will need surveillance to check for subsidence and the integrity of the closures of the mine workings, such as shafts and raises. Disposal of waste material in lakes may need observations to be made of any impacts on aquatic life and checks made for

FIG. 9. Hole in a tailings cover caused by decomposing wood.

dredging and other misuse of sediments. For tailings ponds, surveillance of dam stability, the differential settling of tailings and the functioning of drainage systems are desirable.

The following sections describe the main issues to be considered in surveillance inspections. Although they are primarily applied to above ground impoundments, these issues are considered when carrying out surveillance at all other types of waste management facility dealing with mining and milling waste.

5.3.1. Erosion by water

Erosion by water is often the dominant mechanism leading to dispersion of contaminants from waste management facilities. Water can erode tailings, waste rock, mineralized waste and overburden in a number of different ways. Erosion may be due to overflow of surface water bodies near the waste management facility, river meandering, heavy rainfall runoff or wave action.

5.3.1.1. Erosion due to flooding

If a stream or river overflows its banks at a point near to an above ground waste management facility, the force of the overflowing water could rapidly erode most of the waste piles. The extent of the erosion will depend on the location, depth, velocity and duration of the flooding. This type of erosion is characterized by the undercutting of the slope of the pile. In cases where riprap (loose rock cover) protection is present, a close inspection of the surface is necessary to determine whether any of the rock has been dislodged or whether there has been any damage to the underlying material. Any failure of the rock cover layer is most likely to be due to the washing out of the underlying material. If enough of the underlying material is washed out, a gully may form under the rock layer and eventually cause its collapse. This can be determined by a visual inspection.

5.3.1.2. Erosion due to river meandering

Uranium tailings or mine waste piles located on flood plains may be subject to undercutting and erosion as a result of river meandering. Since meandering involves large areas of the flood plain, aerial photographs can indicate whether the river has changed course in the past. If the tailings pile or mine waste pile is located near a river channel, a detailed contour map is constructed using aerial photography and ground level surveying. Sequential mapping reveals any major shifts in channel position. Recent or periodic bank cave-ins (Fig. 10), which could indicate river meandering, are documented during on-site inspections. Meandering rivers are identified well before they become a problem for the tailings or mine waste management facilities.

5.3.1.3. Surface erosion due to rainfall

Surface erosion may occur as a result of intense rainfall events during which the impact of the rain dislodges soil particles (rain splash), which are then transported by runoff. The erosion rate depends primarily on the duration, frequency and intensity of the precipitation, the vegetative cover, the topography and the physical characteristics of the soil. A serious consequence of surface erosion is the development of gullies (Fig. 11). An initial indication of gully formation is the production of small rills that gradually enlarge as more of the runoff becomes concentrated in the channels.

The side slopes of impoundment embankments are susceptible to gully development, especially if unprotected by a rock or vegetative cover. Early identification of the formation of the rills, followed by prompt remedial action, is the key to avoiding gully formation.

Gullies can develop in the tailings and mine waste piles as a result of several other processes, all of which work in concert with surface erosion in the rapid

FIG. 10. Stream meandering leading to bank failure.

formation of drainage channels. Gullies can develop in low lying areas of the land surface that channel runoff, causing the depth and velocity of water flow to increase as erosion proceeds. Differential settling of the surface of the ponds and piles can produce depressions where runoff can collect and eventually scour a channel. A slump failure of the side slope of the pile can create an unstable bluff face of exposed soil that could easily develop into a gully. Channels that form beneath the soil surface can also lead to the development of gullies when the underground channel becomes large enough to cause the surface to collapse.

It is essential to determine the possible causes of any gullies that develop. If they are caused by erosion due to surface flow, they are monitored using aerial photography and ground surveying. Gullies caused by underground channel collapse are carefully investigated, since such collapse could occur at other locations. If animal burrows are the primary cause, the extent of burrowing and the type of animal are identified to determine the probability of further gullies developing.

FIG. 11. Measurement of erosion gullies.

Surface flow can lead to sheet or rill erosion, in which the surface of an impoundment or a bank is eroded rather uniformly over a relatively large area. This type of erosion can be very difficult to detect visually. The best method for monitoring the rate of sheet erosion is to establish several fixed benchmarks and to check for any significant soil loss with profile surveying and levelling of slope cross-sections. Average annual soil loss amounting to a depth of more than a few centimetres is considered significant.

Stainless steel rods driven several metres into an uncovered tailings or mine waste pile can also be used as benchmarks to estimate erosion rates. However, caution is necessary in using this technique for covered waste facilities so as not to penetrate the clay layer of the cover used to control infiltration. The rods need to extend well below the freeze–thaw level of the soil. The rods need not extend above the surface initially, but could be buried to the depth at which the top of the rod would be exposed and extend above the surface when soil loss becomes significant. Any subsequent exposure of the rods would provide a measure of the average rate of soil loss.

Visual inspection of vegetation on the cover surface for root exposure may also provide an estimate of the amount of erosion. It is more difficult to obtain a reliable measurement of soil loss by this method. Another possible method for measuring sheet erosion is to monitor the accumulation of soil deposits at the base of the tailings or mine waste pile or in sediment and silt traps. The accumulation of soil deposits is often easier to detect than the loss of soil by sheet or rill erosion because the deposits are concentrated in a small area.

5.3.2. Integrity of embankment dams and associated structures

Surface waste management facilities include critical components such as embankments, spillways and other water control structures that have to be regularly inspected. Failure of any of these components could have major socioeconomic and environmental impacts. It is important that the owners and/or operators and regulators be aware of the most common types of failure and their associated early warning signs in order to detect and remedy any abnormal situation promptly.

All embankments are regularly inspected, with particular attention paid to the condition of their crests, abutments, downstream slopes and downstream toes. The main features that could indicate potentially hazardous situations are described in the following sections.

5.3.2.1. Cracks

The crests and downstream slopes of all embankments are closely inspected for the presence of longitudinal or transverse cracks. This is usually done by walking along the crest and the toe of the embankment and, if necessary, up and down the embankment slopes. Short and isolated cracks do not generally indicate a significant problem. However, longer and well defined cracks (wider than 6 mm), exhibiting some relative vertical displacement between the two sides of the crack, may indicate a serious stability problem. All cracks are to be documented, examined by an engineer and adequately sealed to avoid water infiltration. Surveillance of the area will be continued to detect any further movement and may involve accurate surveying for vertical and horizontal movements of the crest and the slopes, or simply observing the relative movement of stakes placed in straight lines in the areas of interest.

Longitudinal cracks running parallel to the crest may signal the early stages of a slide or slump on either face of the embankment (Fig. 12). Surface drying and freeze–thaw cycles could also lead to hairline cracks or relatively wide longitudinal cracks.

Transverse cracks observed across the embankment indicate differential settling along the dam owing to abrupt changes in the condition of the foundation or the properties of the embankment. This type of crack could provide preferential seepage channels and quickly lead to internal erosion (piping) and, possibly, failure of the embankment. When transverse cracks are observed, the downstream slope is to be inspected for any concentrated and turbid or discoloured seepage.

FIG. 12. Cracks and sliding of a pile cover

5.3.2.2. *Slope deformations (bulges and depressions)*

Slopes are closely examined for deformations such as bulges and depressions. Bulges that appear along the slopes or at the toe of an embankment may indicate mass movement of material and constitute an early warning of slope failure. Unlike bulges, the appearance of depressions and subsidence in the downstream slope does not usually indicate a serious threat to the stability of the embankment unless associated with localized high seepage rates. The depressions could simply be filled and monitored.

5.3.2.3. *Seepage*

Seepage may vary in appearance from a soft wet area to a flowing spring and may emerge at different locations along a downstream slope and on the toe and abutments of an embankment. It is essential that the inspector be familiar with critical conditions where seepage may indicate impending failure of an embankment. If one of the following conditions is observed, it is to be reported immediately and closely examined by a qualified engineer.

(a) Soft areas and boils (volcano shaped mounds of fine material) along the downstream slope and toe of the embankment are evidence of piping, also known as internal erosion. Piping is the process whereby fine materials in the embankment and/or the foundation are progressively washed away, creating internal seepage channels which ultimately lead to total failure of the embankment. This phenomenon is most common at the interface between fine and coarse materials, at the abutment contacts and around drainage pipes passing through the embankment. The presence of sinkholes (depressions) on the surface of the tailings upstream of an embankment may also be evidence of internal erosion in the embankment.

(b) Turbid or discoloured seepage may be evidence of internal erosion.

(c) Increased seepage rates or the appearance of new seepage areas may indicate that adverse changes are taking place within an embankment.

(d) Seepage from the downstream face of an embankment, in the absence of toe drains or where existing drains are not functional, could indicate an unusually high water table, which could lead to local sloughing, slope failure and, eventually, piping. High water tables may also be detected by changes in the colour of the slope face and the height, type and colour of the vegetation. It is necessary to verify that existing toe drains remain free flowing and are not clogged by sediment or precipitates.

5.3.2.4. Erosion and slope protection

Erosion caused by runoff usually affects the crests, the slopes and the contacts of embankments with abutments and other structures such as spillways. The most serious form of erosion is the formation of gullies running from the crests to the toes of unprotected embankments. Gullies may quickly increase in size in heavy storms, leading to failure of the embankment. The crests of the embankment need adequate grading to prevent water ponding that could affect the integrity of the embankment in the long term. If inadequately protected, the upstream slopes of an embankment could also be eroded by wave action when there is a water cover over the surface of the tailings.

5.3.2.5. Spillways and other structures used to control the water level

Spillways, decant structures, channels, pipes running through embankments and other discharge structures are to be inspected frequently to ensure that they remain functional. Failure of these components could cause the pond level to rise to hazardous levels in heavy storms, causing overtopping and breaching of the embankments. Pipes and conduits running through the embankments are to be thoroughly inspected for blockages, cracks, corrosion, displacement and signs of other possible mechanisms of degradation.

Spillway outlets are carefully inspected for signs of erosion and undermining, which could damage the spillway and the embankment. Adequate protection is provided to ensure that no erosion takes place, either under normal or extreme flow conditions.

Decant towers and spillway inlets are always kept free of any floating debris that could enter the structures and block the flow. Adequate protection of these structures is provided by means of trash racks.

5.3.2.6. Trees and shrubs

Trees and shrubs on embankments (Fig. 13) are monitored and sometimes controlled. In addition to hindering visual inspection, dense vegetation could cause stability problems. Extensive root systems could provide preferential seepage paths through the embankment, especially when they decay. Fallen or wind blown trees could leave large depressions, increasing the potential for erosion. Finally, dense vegetation may attract burrowing animals that could degrade the embankment. Trees and shrubs are not tolerated in spillway channels, since they may reduce the flow capacity of the spillways.

5.3.2.7. *Animal control*

Rodents and other burrowing animals, which are often attracted by surface impoundments, are normally to be controlled. If embankments are not adequately protected against animal intrusion, burrowing animals could invade both the upstream and downstream slopes (Fig. 14). Extensive burrows may serve as seepage paths through an embankment, causing internal erosion and failure.

Beavers tend to block inlets and spillway channels and raise the water level in the impoundment, posing a serious threat to the integrity of the embankments in heavy storms. Discharge structures are frequently monitored for the activities of beavers and any beaver dam is promptly removed. When the problem is persistent, it might be necessary to remove the beavers from the site or change the design of the discharge structure to discourage their activities.

5.3.2.8. *Concrete structures and mechanical equipment*

All concrete structures are to be regularly inspected for signs of degradation and cracking. Mechanical equipment such as spillway gates and valves and any associated operating and control mechanisms are to be regularly inspected and tested for satisfactory operation.

FIG. 13. Shrubs growing on a covered embankment.

5.3.3. Integrity of waste piles, ponds and covers

Above ground tailing impoundments and waste piles may be stabilized using different types of cover system, including natural soil covers, multilayer engineered covers, vegetation and clean waste rock. These covers are to be regularly inspected to verify their integrity. The main factors leading to the degradation of the covers are erosion, structural instability, biological intrusion and human activity. The same factors will also act to disperse contaminants from uncovered waste piles. The following sections describe issues considered in the surveillance programme. Erosion by water has been described in detail in Section 5.3.1.

5.3.3.1. Deformation of piles and ponds and cracking of covers

Differential settling usually occurs when the foundation of a tailings or mine waste pile allows more settling at one location than another. This could result from

FIG. 14. Hole in an embankment made by a burrowing animal.

heterogeneous or karstic foundation conditions or from non-uniform dewatering of the tailings or mine waste pile. The accompanying deformation would initially lead to cracking of the cover, with one side of the crack normally being lower than the other. Tailings ponds may be deformed by the same processes as tailings piles (Fig. 15). However, ponds are also subject to bulging of the tailings caused by the added weight of the cover on the semi-solid tailings. Bulging tailings and ground failures will break the covers and may actually spill tailings onto the cover surface. Pond covers may also be damaged by the passage of heavy construction equipment. Earthquakes, slumping, settling, bioturbation, freeze–thaw processes or drying of cover material can also lead to the development of cracks. Cracks provide pathways for water to enter the pile or pond and cause erosion or seepage. These cracks could also lead to an increase in the rate of release of radon. The extent of the cracks needs to be noted and photographed during the inspection.

If a riprap layer is in place, it may be difficult to identify minor differential settling because the rock surface is irregular. Any noticeable difference in the elevation of the rock layer is to be investigated to determine whether differential settling has occurred. The integrity of the underlying material is also to be examined in the inspection.

To detect potential subsidence, deformation monuments may be installed on the waste surfaces and routinely checked, using surveying techniques to compare levels against benchmarks off the pile area.

FIG. 15. Differential settling of a pond cover.

5.3.3.2. *Erosion by wind*

Wind erosion is generally much slower than water erosion. Wind erosion can be a concern during the placement of tailings or mine waste before a cover or vegetation is established and on unstabilized or abandoned piles. Erosion by wind is generally difficult to detect visually because this type of erosion often causes a general loss of material rather than a large loss at any one location. The procedures that were described for monitoring sheet or rill erosion are effective in measuring losses due to wind erosion: examination of the exposed roots of vegetation and installation of stainless steel reference rods. There may also be evidence of dune formation in areas downwind of facilities.

5.3.3.3. *Unauthorized human activities*

During the inspection, any indication of removal of material or habitation of the site by humans is noted and photographed. Any activities that could lead to deterioration of the pile are also noted. Such activity could lead to an increased rate of erosion if any cover or stable surface has been disturbed. The removal of tailings or other mine wastes is also a potential hazard to the surrounding population owing to the presence of radiological and non-radiological contaminants.

5.3.3.4. *Growth of vegetation*

Either as a result of seeding designed to stabilize the earth cover after closure, or because of the natural germination of plants, vegetation is likely to become established on tailings and mine wastes piles. On waste rock piles, root penetration is not likely to cause problems. However, plant roots could penetrate a cover overlying tailings or mineralized waste and reach the contaminated material or the soluble contaminants that have diffused upwards through water in the pile and cover. Roots may also reach contaminants drawn upwards by capillary action as a result of evaporation at the pile surface. Soluble material encountered by the roots can become distributed throughout the plants and eventually be deposited on the soil surface when the plants decay. The plants themselves may contain radioactive or toxic material.

Where vegetation is scarce, plants growing on a pile may be used by livestock as food . It is common to have sheep, cattle or other animals grazing on waste disposal piles or remediated open pit mines. These animals may possibly take contamination into their bodies. This is a potential pathway for human exposure. Therefore, plants growing on piles are sampled to determine whether they are absorbing radioactive or toxic material.

Depending on the cover thickness, it may not be desirable to have plants growing on tailings or mineralized waste. If plants are used to stabilize the cover and provide erosion control, only those plants with root lengths compatible with the cover thickness are used. Self-seeded incompatible plants need to be identified and removed. In the case of post-closure inspections, the design specifications for final disposal are consulted to determine the type of plant growth permitted by the design.

5.3.3.5. Burrowing by animals

Extensive burrowing by animals could occur if a rock cover is not adequate or has been damaged, or if layers for the prevention of animal intrusion were not included in the cover design. Burrowing by animals can result in the transport of contaminated material to the surface, increased slumping and erosion, increased infiltration of water into the pile and increased radon flux at the surface. Burrows may also cause structural instability in embankments.

The extent of animal burrowing is observed and photographed each time the pile is inspected. Because the depth and extent of the burrows are specific to the animals concerned, the species involved can be identified. Since some animals prefer slopes, the slopes of the piles are examined carefully when inspecting for evidence of burrowing.

5.3.3.6. Development of salt deposits

In an arid region, evaporation of water at the surface of a covered pile or pond could lead to capillary movement of water towards the surface. This could lead to the transport of water containing dissolved radioactive or toxic material from the underlying tailings or mine waste to the surface. These materials would be left behind on the surface as the water evaporates.

Any salt deposit or standing water that develops on or around the surface of the pile needs to be noted and photographed. Samples of these liquids or salt deposits are collected and analysed to determine whether the salts contain radioactive or other hazardous materials.

5.3.4. Changes in environmental and human receptors

The status of, and changes in, flora, fauna and human receptor populations and population densities and distributions are noted and assessed in relation to the design and performance requirements for the facility. Any changes in human activity in the vicinity, such as changes in land use or construction activities, need to be noted and assessed.

5.4. INSTITUTIONAL CONTROL OF AREAS

Unauthorized removal and use of tailings or mine waste are prevented in order to protect public health and the environment. Passive measures are preferred once the site has been shut down and the waste piles stabilized. If the piles are near an urban area, tails and mine waste may be misused; therefore, these sites are normally enclosed with fences. When fences are used, they need to be regularly inspected to ensure their integrity.

Signs are placed around the tailings and waste piles, warning of the potential dangers arising from the use of the tailings or mine waste or from excavations at the site. Such signs will be needed for hundreds of years and will be more important in the future, when there is a potential for records to be lost or for people to forget the properties of the waste materials. The signs are placed around the tailings pile at locations that will make them easily visible to individuals approaching from any direction. Stone markers are also placed around the site, as these last much longer than conventional signs. The signs and markers are inspected each time surveillance is performed. Signs that have blown down, are missing or are difficult to read are replaced. Stone markers are inspected to ensure that they are legible and not covered with wind blown sand or soil.

Inspectors need to contact local authorities periodically to ensure that they are aware of the facilities and that the authorities understand their responsibilities. Institutional control measures need to be reviewed and verified during the inspection. Violation of controls may lead to increased activity in terms of security, maintenance or inspection to ensure the protection of human health and the environment.

6. REPORTING

Results from the monitoring and surveillance programmes are to be reported to the pertinent competent authority at the requisite intervals on the basis of the nature of the facility and the stage in its life [1].

Environmental monitoring reports are typically submitted monthly, quarterly and annually, although the frequency of reporting may decrease or increase during certain phases of the facility (i.e. more frequent during intense operation periods and less frequent during post-closure). Monthly reports are generally simple listings of all the parameters measured, climatic conditions occuring throughout the month and a summary of any unusual events. Any abnormal readings taken during the month may need reporting immediately to the regulatory authority, depending on the level of the potential environmental hazard. Quarterly reports contain the same types of data as the monthly reports, with an additional brief summary of operational events during the reporting period. These reports may replace the regular monthly report for the month concerned. The annual environmental monitoring report is a summary of the data collected over the entire year and includes extensive interpretation of the significance of the data and a quality assurance assessment. This report is also to confirm that the facility is performing as predicted, as well as being in compliance with all statutory and regulatory requirements. All data are archived for future use.

Surveillance reporting is usually completed within a reasonable period after detailed and special inspections. These surveillance reports normally include the following information:

(a) Date and location of the inspection;
(b) Description of site inspection, results, conditions and recommendations;
(c) Site inspection checklist and any supporting documentation;
(d) Inspection photographs and photographic log sheet;
(e) Recommendations for follow-up inspections, repair or custodial maintenance;
(f) Description and quantification of a problem necessitating corrective actions;
(g) Conclusions and recommendations;
(h) Names, affiliations and signatures of inspectors.

All reports, together with any accompanying sketches, plans or photographs, are archived in a suitable format. This allows a complete site history to be maintained for use in planning future operations, decommissioning and closure. If possible, the records are stored electronically as well as in paper format. Electronic data may be linked to a geographical information system or to databases which allow rapid access to the data for purposes of comparison and modelling. The archive also stores other data that may be useful for surveillance and monitoring tasks, wherever such data are available. These may include aerial photographs and remotely sensed images recorded from various platforms (satellite, aircraft) using techniques such as electromagnetic surveying and infrared imagery.

7. QUALITY ASSURANCE

Monitoring and surveillance programmes should be subject to adequate arrangements as regards quality assurance [1]. Quality assurance provides for a disciplined approach to all activities affecting quality, including, where appropriate, verification that each task has met the objectives and that any corrective action has been implemented.

An adequate quality assurance programme for the monitoring and surveillance programmes has to satisfy the basic general requirements established by the regulatory authority for quality assurance in the fields of environmental protection and radiological protection. These programmes are audited regularly by the regulatory authority.

An appropriate quality assurance programme includes:

(a) Design and implementation of the monitoring and surveillance programmes, including determination of suitable equipment and procedures, and their documentation;
(b) Proper maintenance, testing and calibration of equipment and instruments to ensure that they function properly;
(c) Calibration standards that are traceable to national and international standards;
(d) Quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of the monitoring and surveillance programme;
(e) Uncertainty analysis;
(f) Record keeping requirements.

8. SUMMARY

The key elements necessary to develop an effective monitoring and surveillance programme for mill tailings and mine waste have been discussed in the previous sections. Environmental pathway analysis is important in estimating potential environmental impacts from past, current and future practices in waste management, selecting appropriate locations for environmental monitoring, developing monitoring plans, and in designing and implementing timely corrective measures and closeout options. The development and conduct of an effective monitoring and surveillance plan needs continual interaction between the regulatory authority, the affected community and the mine or mill operators. Figures 16 and 17 show representative flow diagrams depicting this interaction throughout the stages of ore processing and post-closure.

Some of the important goals are to:

(a) Establish a database of the current site specific conditions for safety assessments and design concepts;
(b) Check the effectiveness of engineering designs;
(c) Calibrate models;

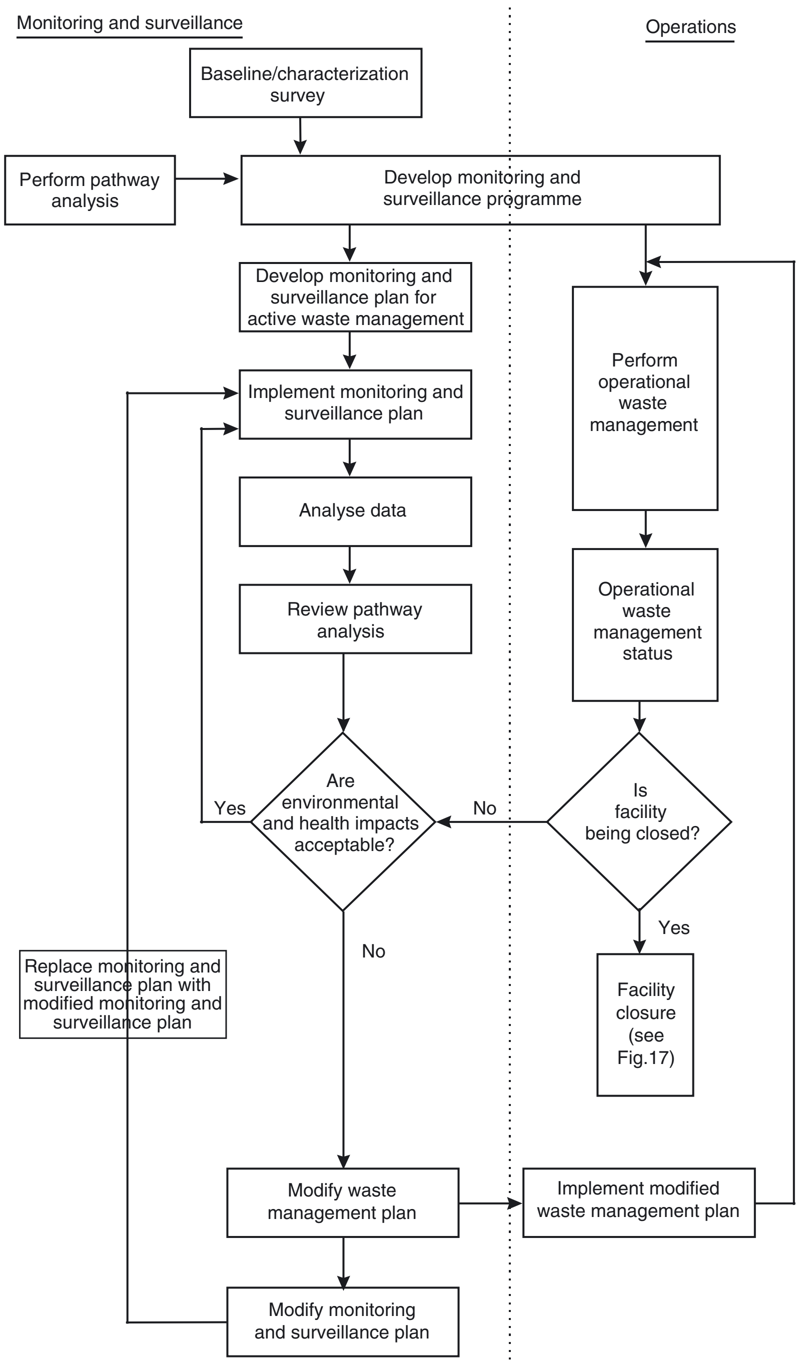

FIG. 16. Steps in the development and implementation of a monitoring and surveillance scheme (operational phase).

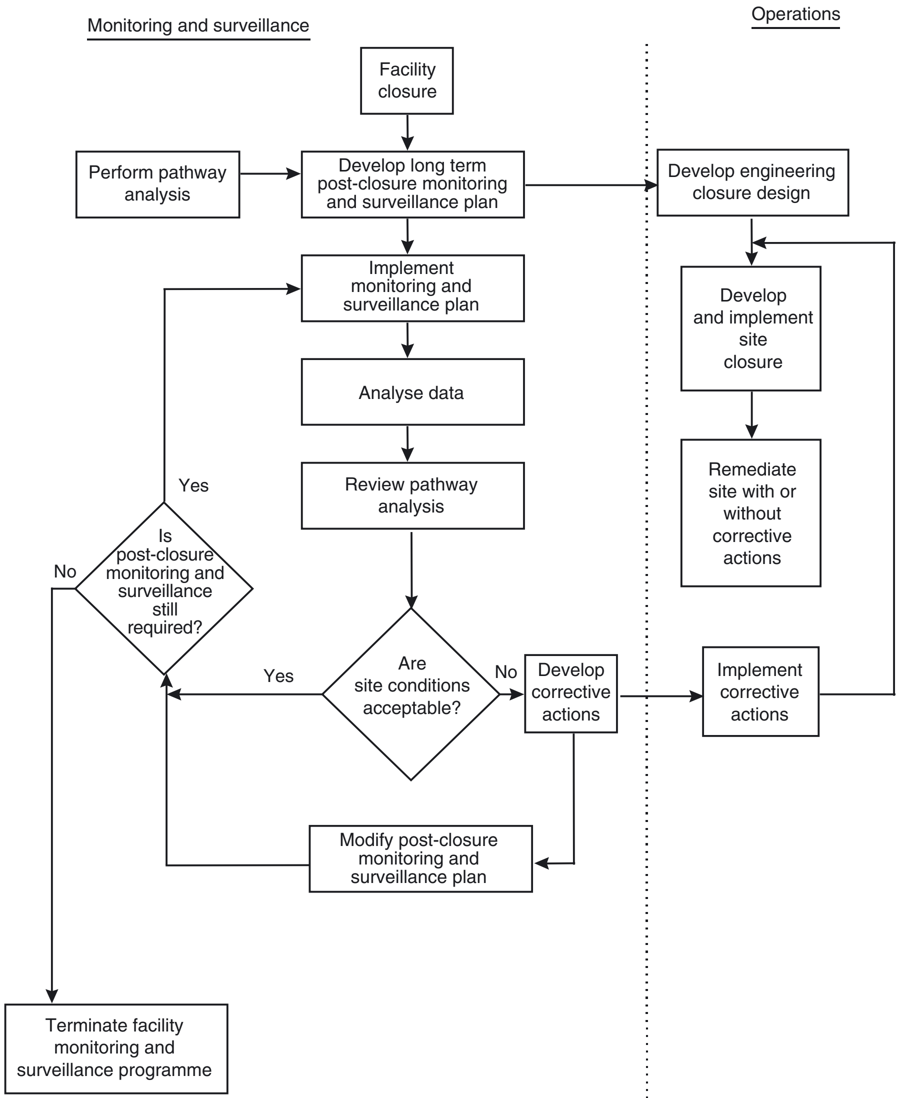

FIG. 17. Steps in the development and implementation of a monitoring and surveillance scheme (post-closure phase).

(d) Provide data for inspections, revisions and investigations;
(e) Detect any environmental impacts;
(f) Assess the condition and integrity of waste management facilities.

The programmes need to be based on site specific safety assessments that are developed as early as practicable. The monitoring needs to include the natural radiation background of the facility as well as an estimate of site specific key parameters of indicators of the environmental impact and of the physical integrity of the waste containment structures.

The baseline data collected prior to the development of the waste management facility are a reference against which the post-closure monitoring results need to be compared. This will be the basis of a final environmental survey and report submitted before the operator's responsibility for the closed and remediated waste management facility is ended. Continued responsibility for stewardship of the waste management facility needs to be established.

Annex I

CONTENTS OF A TYPICAL LONG TERM SURVEILLANCE PLAN

Introduction
- Statutory and regulatory background
- Site history
- Site acquisition and licensing
- Long term surveillance programme

Final site conditions
- Description of the vicinity of the waste management area
- Description of the waste management site
- Access to, and security of, the waste management site
- Design of the waste management area
- Description of adjacent areas

Site drawings and photographs
- Waste management site: baseline map
- Waste management site: as-built drawings
- Site baseline photographs
- Maps and photographs from site inspections

Permanent site surveillance features
- Survey monuments
- Boundary monuments
- Site markers
- Warning signs
- Displacement monuments

Site inspection
- Inspection frequency
- Inspection team
- Preparation for inspection
- Routine site inspection:
  - On-site areas
  - Off-site areas

Environmental monitoring
- Atmospheric
- Water
- Biological

Site inspection documentation
- Site inspection checklist
- Site inspection maps
- Site inspection photographs
- Site inspection report

Unscheduled inspections
- Follow-up inspections after remedial action
- Contingency inspections after unusual events
- Documentation requirements

Institutional control
- Property ownership
- Signs and fences
- Security

Record keeping and reports
- Record keeping requirements
- Reporting requirements

Emergency notification and response
- Interagency agreements
- Notification triggers
- Emergency response

Quality assurance

Personnel health and safety
- Health and safety during inspections
- Reportable incidents

References

Annex II

TYPICAL SITE INSPECTION CHECKLIST

SITE INSPECTION CHECKLIST FOR THE *SITE NAME, COUNTRY OR STATE* MILL TAILINGS DISPOSAL SITE

Date of last inspection: Reason for last inspection:

Responsible organization:

Address:

Inspection start date and time:

Weather conditions at site:

Inspection completion date and time:

Inspector: ____

Name Title Organization

A. GENERAL INSTRUCTIONS

1. All checklist items must be completed and comments made to document the results of the site inspection. The completed checklist is part of the field record of the inspection. Additional pages should be attached, as necessary.

2. Any derogatory item that is checked by an inspector must be explained or appropriately referenced. Explanations are to be placed on additional attachments and cross referenced. Sketches, measurements and annotated site atlas overlays will be added if necessary.

3. The site inspection is a walking inspection of the entire site, including the perimeter and sufficient transects to inspect the entire surface and all features specifically described in this checklist. Every monument, site marker, sign, monitoring well and erosion control marker will be inspected.

4. Monitoring plant growth and assessing the need to control vegetation should take place during the site inspections. The species of plant and the extent of plant coverage on the facility should be determined and documented in the site inspection reports.

5. A set of photographs will be taken for comparison with baseline photographs to reveal any significant differences in site appearance. In addition, all anomalous features or new features (such as changes in adjacent area land use) must be photographed. A photographic log will be made for each photograph taken. The photographic log is part of this checklist.

6. Field notes will be taken and recorded in a bound book with numbered pages to assist in completion of this checklist, which will become part of the inspection record. No form is specified; the field notes must be legible and contain sufficient detail to enable review by succeeding inspectors and the responsible agency.

B. PREPARATION (to be completed prior to site visit)

	Yes	No
1. Licence and/or long term surveillance and maintenance plan reviewed	______	______
2. Site as-built plans reviewed and base map with copies of the following site atlas overlays obtained:		
(a) Adjacent off-site features and land use, fences and signs, access roads and paths	______	______
(b) Survey monuments, boundary markers, site markers, aerial photograph ground controls, ground photograph locations	______	______
(c) Monitor wells, site drainage, diversion channels	______	______
(d) Planned inspection transects and vegetative cover	______	______
(e) Other (state item)	______	______
These overlays will be used to identify site features and record appropriate field data.		
3. In previous inspection reports reviewed:		
(a) Were anomalies or trends in modifying processes detected on previous inspections?	______	______
(b) Was custodial maintenance performed?	______	______

	Yes	No
(c) Was contingency repair work done as a result of the inspection?	______	______
4. In site custodial maintenance and contingency repair records reviewed:		
(a) Has site contingency repair resulted in a change from as-built conditions?	______	______
b) Are reviewed as-built drawings available that reflect contingency repair changes?	______	______
5. If required, has adjacent property entry approval been obtained (if yes, attach signed access agreement)?	______	______
6. Aerial photographs reviewed, if taken since last inspection	______	______
For each set, enter date taken, scale, and whether interpreted	______	______
The following standard disposal site features are documented with photographs as needed to compare with baseline photographs:		
(a) Permanent site surveillance features	______	______
(b) Fences, gates, access roads, perimeter road and paths	______	______
(c) Drainage channel or other diversion channels	______	______
(d) Trench drains	______	______
(e) Groundwater monitor wells and other monitoring locations	______	______
(f) The waste management area (top, sides, apron and surrounding area) — panoramic sequences of photographs from selected vantage points may be used for this purpose	______	______
(g) Any evidence of erosion (e.g. gullies, rills) the inspector considers significant and which is included in the text of the inspection report	______	______
(h) Off-site features that may affect the site in the future	______	______
(i) Vegetation (site area, cover and unwanted plant growth)	______	______

	Yes	No
(j) Erosion protection material (riprap)	_______	_______
(k) Potential problem areas	_______	_______

7. Examine aerial photographs to determine if they suggest any of the following (if yes, give photograph set date and location, and indicate if item noted by interpreter or inspector):

	Yes	No
(a) Human intrusion	_______	_______
(b) Animal intrusion	_______	_______
(c) Channelled erosion on slopes	_______	_______
(d) Change in area drainage	_______	_______
(e) Landslides	_______	_______
(f) Creep on slopes	_______	_______
(g) Obstruction of diversion channels	_______	_______
(h) Bank erosion of diversion channels	_______	_______
(i) Seepage	_______	_______
(j) Cracking	_______	_______
(k) Change in vegetative cover	_______	_______
(l) Displacement of fences, site markers, boundary markers, or monuments	_______	_______
(m) Change in adjacent land use	_______	_______
(n) Evidence of tailings or waste exposure or transport	_______	_______

8. Examine as-built drawings or subsequent inspection reports, noting distance and azimuth from designated site location, such as a monument, to adjacent off-site features that eventually could affect site integrity

	Off-site feature	Site monument no.	Distance	Azimuth
(a)	_____________	________________	_________	________
(b)	_____________	________________	_________	________
(c)	_____________	________________	_________	________

	Yes	No
9. Assemble the following equipment, as needed, to conduct inspections:		
(a) Cameras, film and miscellaneous support equipment	______	______
(b) Binoculars	______	______
(c) Tape measure	______	______
(d) Optical ranging device	______	______
(e) Compass or global positioning system	______	______
(f) Photograph scale stick	______	______
(g) Erasable board	______	______
(h) Plant press and plastic bags for vegetation	______	______
(i) Keys to locks	______	______
(j) Bolt cutters	______	______
(k) Hand lens	______	______
(l) Clipboard	______	______
(m) Bound, numbered field notebook	______	______
(n) Other (state item)	______	______

C. SITE INSPECTION

	Yes	No
1. Inspect adjacent off-site features (within 0.4 km of the site boundary) for the following:		
(a) Changes in use of adjacent areas (grazing, construction, agriculture)	______	______
(b) New roads or trails	______	______
(c) Change in the position of nearby stream channels	______	______
(d) Erosion of nearby gullies	______	______
(e) New drainage channels	______	______
(f) Other (state item)	______	______

	Yes	No
2. Inspect access roads and paths, fences, gates and signs for evidence of the following:		
(a) Break in the fence	______	______
(b) Damage to posts or weakened anchoring	______	______
(c) Erosion or digging beneath the fence	______	______
(d) Tampering or damage to the gate	______	______
(e) Human intrusion	______	______
(f) Intrusion by large animals	______	______
(g) Damage to, or removal of, signs (number of signs replaced: __________)	______	______
(h) Road or access obstruction	______	______
(i) Excessive new plant growth	______	______
(j) Other (state item)	______	______
3. Examine monuments and other permanent features for evidence of the following:		
(a) Disturbances to survey or boundary monuments	______	______
(b) Disturbances to site markers caused by humans or natural processes	______	______
(c) Integrity of monument or site markers threated by natural processes	______	______
(d) Monuments or other features hidden or covered by plant growth	______	______
(e) Other (state item)	______	______
4. Examine crest for evidence of the following:		
(a) Uneven settling (depressions, scarps)	______	______
(b) Cracking	______	______
(c) Breach in the outer cover layer	______	______
(d) Erosion:		
(i) By water (rills, rivulets)	______	______
(ii) By wind (pedestal rocks, ripple marks)	______	______

	Yes	No
(e) Changes in vegetative cover (not as described in the as-built drawings)	______	______
(f) Animal burrowing	______	______
5. Examine slopes for evidence of the following:		
(a) Downslope movement (creep terraces, deflection of plants)	______	______
(b) Cracking	______	______
(c) Depressions or bulges on the slope	______	______
(d) Breach in the outer cover layer	______	______
(e) Erosion:		
(i) By water	______	______
(ii) By wind	______	______
(f) Channelled water runoff (rivulets, gullies)	______	______
(g) Seepage (moisture, colour, vegetation)	______	______
(h) Significant changes in vegetative cover since the last inspection	______	______
(i) Animal burrowing	______	______
(j) Deterioration of riprap or gravel cover	______	______
(k) Other (state item)	______	______
6. Examine the periphery (within site boundaries) for evidence of the following:		
(a) Seepage, such as wet areas or localized change of vegetation	______	______
(b) Sediment transport from the tailings pile by water or wind	______	______
(c) Changes in vegetative cover (not as described in the as-built drawings)	______	______
(d) Changes in drainage (not as described in the as-built drawings)	______	______
(e) Other (state item)	______	______

	Yes	No
7. Examine diversion channels for evidence of the following:		
(a) Bank erosion	______	______
(b) Disturbance of lining or riprap structure by humans or natural processes	______	______
(c) Channel erosion	______	______
(d) Sedimentation in the channel	______	______
(e) Obstructions in the channel	______	______
(f) Diversion channels not functioning	______	______
(g) Excessive plant growth	______	______
(h) Other (state item)	______	______
8. Examine monitor wells for evidence of the following:		
(a) Disturbances by humans or natural processes	______	______
(b) Potential threat to the integrity of any monitoring well by natural processes	______	______
(c) Missing caps or locks	______	______
(d) Plant growth that covers or hides a well	______	______
(e) Other (state item)	______	______

D. FIELD CONCLUSIONS

1. Is there an imminent threat to the integrity of the tailings pile (if yes, immediate report required)?	______	______
Inspector: __________________		
Agency to which report made: __________________		
2. Are more frequent inspections required?	______	______
3. Are existing contingency repair actions satisfactory?	______	______
4. Is a follow-up inspection required?	______	______
5. Is a contingency report or custodial maintenance required?	______	______

	Yes	No
6. Is the rationale for field conclusions documented in the text of this report?	______	______
7. Do access controls or other institutional controls appear to be effective ?	______	______

SITE INSPECTION PHOTOGRAPH LOG (attached) ______ ______

CERTIFICATION (when appropriate) ______ ______

I have conducted an inspection of the *Site Name, Country or State,* waste management site in accordance with the procedures of the licence (including the site surveillance plan) as recorded on this checklist, attached sheets, field notes, photograph log sheets and photographs.

______________________ ______________________

Inspector's signature Printed name

______________________ ______________________

Title Date

Annex III

EXAMPLE SITE INSPECTION PHOTOGRAPH LOG

Site: ____________________ Site activity: ____________________________________

Date:_________ Time: from _________ to _________

Weather conditions: ____

Roll number: _______ Film type: _____________

Number of exposures: ________________________

Photograph number	Location and direction	Description

____

Name of photographer

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CONTRIBUTORS TO DRAFTING AND REVIEW

Belfadhel, B.	Canadian Nuclear Safety Commission, Canada
Bruno, H.	Autoridad Regulatoria Nuclear, Argentina
Falck, W.	International Atomic Energy Agency
Frost, S.	Cameco Corporation, Canada
Gonzales, D.	Jacobs Engineering Group, United States of America
Haehne, R.	C&E Consulting and Engineering GmbH, Germany
Harris, F.	International Atomic Energy Agency
Jacobson, C.	MACTEC Environmental Restoration Services, United States of America
O'Brien, R.	Australian Radiation Protection and Nuclear Safety Agency, Australia
Pather, T.	Council for Nuclear Safety, South Africa
Reisenweaver, D.	International Atomic Energy Agency
Waggitt, P.	Office of the Supervising Scientist, Australia