Occupational radiological safety in uranium mines and mills

by J.U. Ahmed*

Uranium mining and milling industries are growing rapidly in many countries and this trend is likely to continue with the increasing demand for nuclear fuel. The problems of radiological hazards in this part of the nuclear fuel cycle have received considerable attention in recent years because of the epidemiological evidence of lung cancer among uranium miners, mainly smokers. The hazard is not limited to uranium mines only: investigations having shown that the same radiological constituents that have caused lung cancer among uranium miners, i.e. radon and its decay products, occur in other types of mines; and, in some instances, they occur in sufficient concentration to cause occupational illness.

In uranium mines the radiological hazards are primarily due to the airborne radionuclides which consist of radon and its short-lived daughter products, Po-218, Pb-214, Bi-214 and Po-214. Radon (Rn-222) is an inert gas, therefore it passes freely into and out of the lung with minimal uptake by the respiratory system. On the other hand, radon daughters are solids and can get attached to dust particles in the air. Inhaled radon daughters deposit preferentially in the respiratory tract, the exact location depending on their particle sizes. The magnitude of the radiation dose to the respiratory system depends on the concentration of the radon daughters in the inhaled air, the size of particles in the dust to which the daughters are attached, and physiological parameters.

Single atoms, known as uncombined radon daughters, are thought to deposit preferentially in the upper passages of the respiratory tract where most miners' lung cancers develop. The proportion of uncombined radon daughters is low: a study showed the fraction to be in the range from 0.002 to 0.12, more than half the values being less than 0.03.

The airborne radioactivity in the mine also contains long-lived radionuclides from the U-238 and U-235 families. From the viewpoint of internal contamination U-238, U-234, Th-230, Ra-226, and Po-210 are significant. Mining operations, such as drilling and blasting, produce airborne dust containing these long-lived nuclides which, in most ores, are close to radioactive equilibrium.

External radiation hazards in uranium mines are due to beta and gamma radiation emitted from the ore bodies. The external radiation levels in most mines are generally low and do not pose significant problems In mines where the ore grade is relatively high external radiation does constitute a significant hazard.

In uranium mills, radon and its daughters usually present only a minor inhalation hazard compared to ore and uranium dusts, although significant radon concentrations may occur near ore storage bins, and crushing and grinding circuits. Typical dusty operations are ore crushing and grinding and final product preparations. At the initial stages – crushing and screening – the long-lived radionuclides tend to be in equilibrium, but during subsequent operations this equilibrium is disturbed. At the precipitation and recovery section the solutions and solids handled are rich in uranium so that the airborne radioactivity is predominantly due to uranium. In tailing treatment areas the airborne radionuclides are predominantly Th-230, Ra-226 and polonium.

The exposure of workers in uranium mills to external beta and gamma radiation is generally comparable to that of workers in uranium mines but it may be significantly higher in some locations. The external radiation levels vary from mill to mill depending on the grade of ore, type and grade of concentration, and type of process, but generally, external radiation hazards assume significance mainly in the final stages of precipitation, filtration, concentrate packing, and storage. Freshly separated uranium is primarily an alpha-emitter, but as daughter products build up, both beta and gamma activities also build up. In about 24 days 50% of the equilibrium beta-gamma activity is reached. Thus in the product storage area the radiation levels will increase with time of storage of the product.

Surface contamination, if not controlled by proper containment and regular housekeeping, can contribute to airborne activity through resuspension. This is a significant problem mainly where concentrates are handled such as in the precipitation, filtration, weighing and packing areas. Tailings treatment areas are also susceptible to significant surface contamination.

Radioactive waste, both solid and liquid, can be another source of radiation hazard to workers in uranium mines and mills. The special precautions that are taken to

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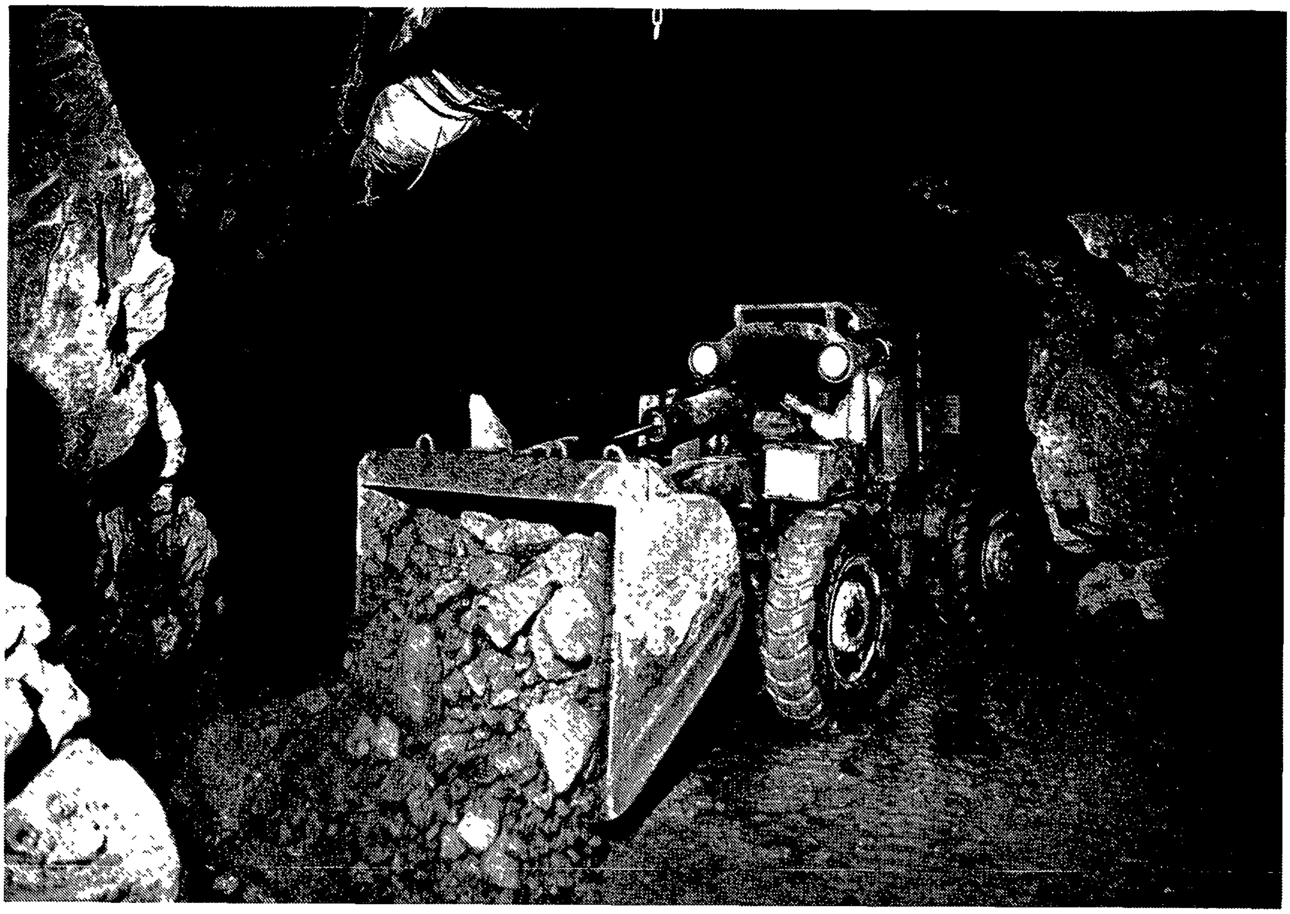


Inside an underground uranium mine in the Vendée region of France.

deal with radioactive wastes from mining and milling are the topic of the following article in this issue of the IAEA Bulletin.

Dose limits

In mining and milling of uranium the control of exposure of workers to radon daughter products is of utmost importance. The basis for setting the limit for radon daughters is the limit on effective dose-equivalent of 50 mSv (5rem) in a year The International Commission on Radiological Protection (ICRP) has recommended a limit for intake by inhalation, the ALI, for Rn-222 daughters. This is expressed in terms of the potential energy released by the inhaled radioactive elements. The ICRP limit is 0.02 joules in a year. The corresponding derived air concentration, expressed in a practical unit which has been widely used, is then 0.4 working level (WL). The working level is the sum of the alpha energies released by the decay of radon daughters which are in equilibrium with 3.7 Bq (100 pCi) radon. This amounts to 1.3×10^5 MeV/litre. Therefore, one working level represents any combination of the short-lived radon daughters in one litre of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha energy, taking no account of radon. If one worker is exposed to a radon daughter concentration of 1 WL for 1 working month then the exposure is expressed as 1 working level month (WLM). The annual limit expressed in WLM is $0.4 \times 12 = 4.8$ i.e. 5 WLM.

The system of dose limitation of ICRP requires the addition of exposures to external radiation and intakes of radioactive material. In uranium mines this additivity has the effect of requiring the inhalation of radon and its daughters to be kept below the recommended limit by an amount that depends on the exposure to external radiation and ore dust. The combination formula is·

$$\frac{H_E}{50\ \text{mSv}} + \frac{E_{RnD}}{0.02\text{J}} + \frac{E_{OD}}{1.3\ \text{Bqh l}^{-1}} \leqslant 1$$

where H_E = Exposure to external radiation, expressed in effective dose-equivalent (mSv);

E_{RnD} = Exposure to radon daughters, expressed in joules;

E_{OD} = Exposure to ore dust (other than radon daughters), expressed in becquerel-hour per litre.

The denominators are the corresponding annual limits. The annual limit of intake by inhalation of respirable ore-dust is 1.3 becquerel-hour per litre (Bqh l^{-1}).

For practical purposes, other limits are often set in addition to primary dose-equivalent limits. Authorized limits are set by the competent authority or the management and are generally lower than the primary or derived limits. When authorized limits are specified by the management, they are designated as operational limits Reference levels may be established by the competent authority for any of the quantities determined in the course of radiation protection programmes, whether or not there are limits for these quantities. A reference level is not a limit, but it is useful in determining a course of action when the value of a quantity exceeds or is predicted to exceed the reference level The most common forms of reference levels are the recording level, investigation level, and intervention level. Recording level is the dose-equivalent or intake level above which the monitoring result is of sufficient interest to be worth recording and keeping. Investigation level is the monitoring result indicating potential dose-equivalent or intake limit above which the result is considered sufficiently important to justify further investigation. The intervention level is a pre-determined level above which action should be taken to reduce the level of radiation or remove personnel from exposure to that level until corrective actions can be taken to reduce the level to an acceptable value.

Monitoring

The principal objectives of monitoring are to evaluate occupational exposures with respect to accepted standards, and to provide data for adequate control. For the latter, monitoring can serve the following functions: detection and evaluation of the principal sources of exposure; evaluation of the effectiveness of the control equipment, detection of anomalies in operation; and prediction of the effect of future operations on contamination levels.

The relative emphasis on different types of monitoring depends on the degree and types of hazard In uranium mines, the radon daughters constitue the dominant hazard and therefore require continual monitoring. Next in order of importance are external radiation and then ore dust. In mills, the order of hazards varies with the particular phase of the process. In the ore storage, grinding, and classifying areas, ore dust presents the dominant source of exposure, radon daughters occur in low to moderate concentrations, and external radiation is minimal. In product areas, concentrate dust is the principal source of exposure although external radiation intensities may be high enough to warrant surveillance, radon daughters are insignificant or absent. At intermediate processing areas, both external radiation and airborne radionuclides are detectable but tend to be of minor importance.

Exposure to radon daughters by inhalation is the dominant occupational health hazard in uranium mines and warrants the greatest proportional effort in the monitoring programme. In mines, virtually all monitoring is done by collecting samples manually in short time periods. Such grab samples indicate radionuclide concentrations only at the time and location of collection and, consequently, sampling must be repeated periodically wherever average concentrations have to be known

Personal radon-daughter monitors have been developed in recent years, based on etched track technique, but these have not yet been used on a wide scale.

Ore-dust concentrations for the most part are dependent on mining operations, and a miner's exposure to ore-dust may be strongly influenced by his proximity to radiation sources Consequently, air samples should be collected very close to the miner to measure his exposure accurately, but ore-dust concentrations in the mines are low enough so that this precaution is not always necessary.

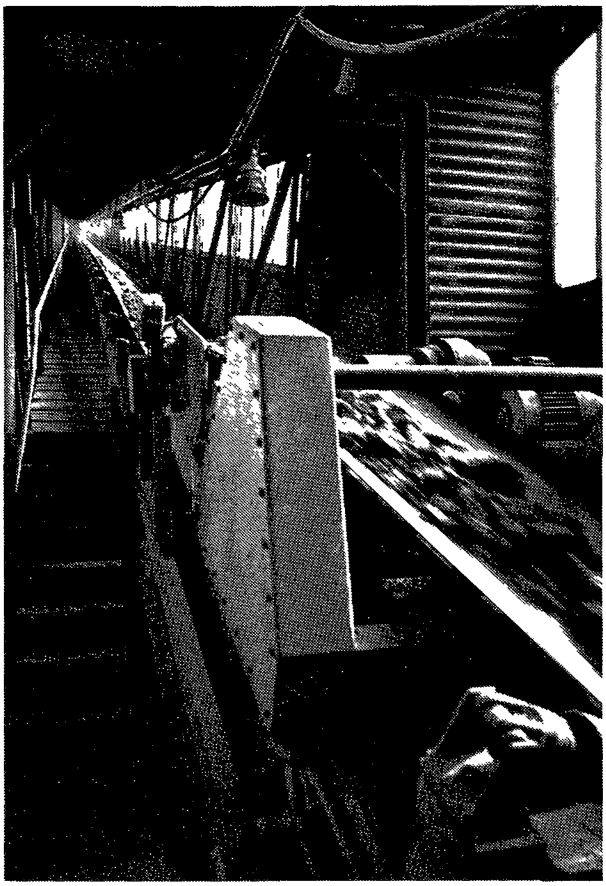
Air monitoring in mills is also primarily by means of grab sampling but personal air samplers can be used for measuring individual exposures to ore-dust and concentrate dust. Most airborne contaminants in mills derive from localized sources, resulting in sharp concentration gradients in the vicinity of points of release. Consequently, the location of grab samples for exposure monitoring is more critical than in mines and a greater frequency of repeated measurements is required because of greater variation. In areas of dusty jobs such as emptying dust collectors, filling product drums, processing ore and concentrate samples, breathing zone samplers may be required when personal air samplers are not being used.

External radiation is monitored with survey instruments and individual dosemeters.

Protection measures

The methods of maintaining a safe working environment are basically the same in uranium mines as in conventional mines but the unique properties of radon and radon daughters impose special requirements, particularly in regard to ventilation. For a given radon concentration, the daughter concentrations and hence the hazards increase rapidly with time because of short half-lives of radon daughters. Therefore, the more rapidly contaminated air is removed from work areas, the lower will be the concentration of radon daughters in any given location. Basic methods of control in order of importance are. mechanical dilution ventilation, confinement or suspension of radiation source, and personal protection and job rotation. Air cleaning for the removal of radon daughters is being used on a limited basis as a supplement to mechanical ventilation

Primary and auxilliary systems of mechanical ventilation are used to dilute the radon and radon-daughter concentrations in the mine air. The primary ventilation moves dilution air into, through and out of the mine via shafts and drifts by means of large fans usually located at the surface. Auxilliary systems distribute air from the main air courses to locations underground by means of



The conveyor belt taking ore to the processing plant of l'Ecarpière in the Vendée, France.

small fans and flexible ducts. Auxilliary systems are extended, modified or replaced as the mine layout changes.

Radon and radon daughters in worked-out areas can be confined and prevented from entering into the working areas by means of stoppings made as air-tight as possible. As radon is soluble in water and emanates from seepages upon exposure to the mine atmosphere, using pipes for sealing or diverting water is another useful confinement technique. Suppression of radon emanation from mine surfaces by pressurizing the mine atmosphere is feasible if the rock is porous. The use of coatings has been found to be useful in sealing the pores and crevices of exposed rock surfaces.

Personal protective equipment such as respirators are used on a non-routine basis in areas where airborne dusts are high. Job rotation is recommended in mines having areas with high levels of external radiation for which no practical means of control are available.

In mills, the control measures to protect the health of workers differ in degree and kind from those applied in underground operations Primary control is achieved by confinement, although local exhaust ventilation is used extensively to prevent the escape of dust, gases, and fumes from the operations. The processes in the mill are largely automated, thus minimizing direct contact with materials on the part of the mill workers. The working practices are designed to reduce the likelihood of contaminant release, and proper housekeeping is performed regularly to remove contaminants that have accumulated on surfaces.

Thorough personal hygiene should be required of all personnel in contact with uranium concentrates. Washing before eating or smoking, and showering at the end of each work shift should be mandatory. Gloves should be worn for any direct contact with concentrates. Lunch rooms, rest rooms, and changing rooms should be isolated from working areas, and provided with convenient access to washing facilities.

Personal respiratory protection is merely an adjunct to engineering control measures. Primary emphasis always should be on maintaining the radionuclide air concentrations in the working environment within permissible limits. However, respirators or breathing apparatus are necessary in some, usually exceptional, circumstances such as during failure of the ventilation system or during a maintenance task for which adequate ventilation is not available. The use of respirators is not compatible with work involving sustained physical effort or complete freedom of movement.

All persons employed in mining and milling of uranium should be medically examined before such work and at appropriate intervals thereafter. The pre-employment and periodic medical examinations should be adequate to provide information on the general health of the worker and to prevent and detect changes which may be related to his occupational exposure.

The pre-employment examination should be a thorough examination. In general, periodic examinations should be done at yearly intervals for exposed workers. The periodic examinations should include an enquiry into the general health of the worker, with special emphasis on certain organ systems. A medical examination should be carried out at the termination of employment.

Need for improvement

Present monitoring and control technology is adequate for maintaining safe working environments both in mining and milling of uranium. Compared to other technologies applied in the nuclear industry, little research and development has been done on monitoring and control in mining and milling. In recent years this area has been given considerable attention, however, there is a need for improvements in all aspects of monitoring and control.