THE RADIOLOGICAL IMPACTS OF URANIUM MILL TAILINGS - A REVIEW WITH SPECIAL EMPHASIS ON THE TAILINGS AT RANSTAD IN SWEDEN

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Abstract

The environmental impact of uranium mill tailings can be expressed in collective dose commitment and corresponding detriment per $MW_e \cdot y$ energy produced by the uranium which corresponds to the amount of waste of interest. The methods of dose commitment calculations are discussed and it is suggested for the purpose of estimation of the detriment to limit the commitment to 10,000 years.

The external radiation from the tailings is easily reduced by covering but in case of a future settlement on the tailings the collective dose commitment will be some hundreds to thousands of manrad/$MW_e \cdot y$ depending on the quality of the uranium ore.

The dispersion of dust from uncovered tailings is mainly a local problem and the collective dose commitment for critical tissues in the lung will be less than a manrad/$MW_e \cdot y$.

In the long run the cover may be lost and the resultant collective dose commitment for the critical tissues in the lung will be a few tens of manrad/$MW_e \cdot y$ depending on the quality of the tailings. The effects of global dispersion of the material in the tailings are also discussed.

1. INTRODUCTION

Mining and milling of uranium result in the formation of waste products formed in the various stages of the process. These affect the environment to varying degrees and they must be suitably disposed of. They consist of solid wastes, mainly from the mining process, liquid wastes which are residues from the milling processes or leakage during the milling, and airborne waste in the form of dust chemical contaminants and radioactive substances, principally radon. The final stage in the milling process involves storage of the mill tailings and it is this which represents one of the main waste disposal problems.

The consequences for the environment depend on the working and milling techniques, on the protective measures applied and on the appearance and nature of the environment with regard to the vegetation, buildings and general land usage. During the decades during which uranium mining has been in progress, increased insight has been obtained on the composition and environmental impact of the wastes and stricter requirements have been imposed for purification plant, retaining systems and supervision.

The releases and leakage which can adversely affect the environment contain radioactive substances, metals and different chemical compounds. The radioactive substances, above all uranium, radium and radon, are dispersed in the environment via water or air and they can irradiate humans either internally after uptake in the body via water, foodstuffs or air or externally from deposits on the ground. However, due to radioactive decay and dispersal in the environment the environmental impact of the radioactive substances will be limited in time.

The radioactive substances may become enriched in plants and animals and the equilibrium levels reached after many years' release may constitute one reason for instituting release limitation and supervision. A great deal is now known concerning radiological uptake and enrichment processes and - by using pessimistic values in the assessment - it is possible to predict the consequences for the environment, including man, of radioactive releases over a long period of years. When estimating the resultant radiation doses and their consequences, the dispersion and uptake must be taken into account even at points far remote from the point of release. In principle it is the consequences of global dispersion which are calculated if such dispersion can be anticipated. The resultant collective dose, i.e. the sum of all the individual doses, expressed in manrads is calculated in relation to the energy produced expressed in MW_e·year (MW_e means megawatts of electric power) which the practice has given rise to.

Since a release of radioactive substances with long half-lives will remain in the environment for many years, the collective dose is calculated taking into account this residence effect. It is then called the collective dose commitment. In principle, the collective dose commitment can be calculated for the whole period for which the released pollutant remains in the environment and can affect humans. For radioactive substances this means in practice for a finite time of the same order of magnitude as the half-life and for stable substances it means an infinite time. However, the longer the time perspective considered, the greater the uncertainty when predicting the behaviour of a pollutant in the environment. Periods of time with an order of magnitude exceeding 10,000 years may include one or more ice ages and are therefore extremely speculative and uncertain. In such cases calculations are therefore probably meaningless.

To estimate the collective dose commitment and the consequences in terms of the probable number of cases of cancer resulting from a particular practice, for instance uranium mining, the effects for this purpose have been calculated for a maximum period of 10,000 years.

Strictly speaking, the consequences of the releases of non-radioactive substances should be calculated in the same way. The environmental impact of these substances, however, is usually reported in the form of concentrations in air, water, plants and animals where these concentrations are related to the toxic limits. The results are usually also handled in a different way with regard to the effects on man. For radioactive substances and ionizing radiation the possible effect on man is calculated even for very low radiation doses. In the case of other substances, however, it is common to refer to threshold values below which the risk of injury can be neglected. A comparison between the risks on this basis is therefore unsatisfactory. In spite of this fact it has been found that it is often the effects of the non-radioactive substances which determine the limits which must be set. When the releases and leakage of these substances is limited to comply with these limits the conditions for the radioactive substances may be fulfilled automatically, possibly with the exception of the leakage of the gas radon and the external radiation from the piles of mill tailings both of which necessitate special remedial measures.

2. THE MILL TAILINGS PILES

2.1 General

The wastes from uranium production which have attracted most attention are those known as mill tailings. They consist of the uranium-depleted ores, sometimes with additives such as limestone to achieve chemical neutralization. Initially, the consistency of mill tailings is semi-liquid but after evaporation and drainage they gradually become solid. The quantities are of the same order of magnitude as those of the ore taken from the mine and are therefore greater when the uranium content of the ore is smaller. In the USA the quantities are now of the order of 100 million tons. If 1 300 tons of uranium were mined annually in Ranstad, 6 million tons of mill tailings would be obtained each year.

Mill tailings are laid out in piles, the height of these piles varies from country to country, from roughly 5 to 30 metres. An annual production has an area of 0,1 - 1 km^2. The area can also be expressed in terms of the energy produced from the extracted uranium. For the USA this value has been given as 8 m^2/MW_e·year and for Sweden 25 m^2/MW_e·year, due to different uranium contents and techniques for making the piles. The leaching process gives a uranium yield of 70 - 95 per cent. Thus 5 - 30 per cent of the initial content of uranium is present in the tailings. Furthermore, the tailings contain almost 100 per cent of the other radioactive substances, including thorium-230 (half-life 83,000 years) and radium-226 (half-life 1,600 years).

The mill tailings piles can affect the environment due to leakage from the piles of heavy metals, chemical compounds and radioactive substances via water, via airborne dispersal of radon and solid particles. In addition, in the immediate vicinity of the piles there is a weak gamma radiation field.

The environment can be protected by isolating and stabilizing the mill tailings. The piles are impounded in earth walls, stabilized chemically with neutralizing substances and mechanically by the admixture of non-radioactive rock waste and covered with moraine and topsoil. This prevents more than a very limited seepage of precipitation through the tailings with concomitant leaching out of substances deleterious to the environment.

The experience gained from modern installations shows that the leach-out of radioactive substances is normally very slight. However, the chemical properties of the mill tailings and the filler material affect the leach-out process. For example, the presence of Cl-ions increases the leach-out of radium (1). The pyrities content of certain ores may lead to the formation of sulphuric acid in the tailings due to chemical and bacteriological oxidation and this may lead to crumbling of the tailings and increased leach-out of deleterious substances. This effect can be reduced by the addition of limestone.

2.2 External radiation

The gamma radiation from mill tailings originates mainly from the progeny of radon. The precursor of radon is radium-226 which - as in the case of the precursor of radium, thorium-230 - is present in the same quantities in the tailings as in the original uranium ore. This gamma radiation will be practically unchanged for the whole foreseeable future. It will be 80,000 years before the level has decreased to half.

However, as an environmental hazard from a short term point of view (hundreds of years) the gamma radiation from the tailings is a fairly limited problem. It affects mainly the actual area occupied by the tailings and results in an unacceptable exposure level in the case of long-term occupation of the area. The tailings from the milling of uranium ores with contents of 0.03 - 0.3 per cent give about 0.2 - 2 mrad/hour on the surface, i.e. some 40 - 400 times the level of the normal natural background radiation from the ground. By covering the tailings with layers of moraine and soil several metres thick the gamma radiation can be effectively shielded off. Decisions concerning the future use of the area covered by the mill tailings must therefore take into account the risk that the covering layer of moraine may be removed with the result that the gamma radiation again becomes unacceptably high.

If the covering layer of moraine should be removed, either by wind and erosion or by some human action, and persons unaware of the radiation risks should take up residence in the area, they would be exposed to gamma radiation levels of the order of 0.2 - 2 mrad/ /hour. However, one can assume some degree of shielding from the layer of topsoil added to make the building site attractive. In addition, the building materials in a house provide some shielding. Therefore, a more reasonable value of the gamma radiation level would be about a tenth of the values above.

The annual individual risk of injury (cancer) from this cause would be 0.003 - 0.03 per cent. If the presence of a community of 10 000 persons is assumed, the collective dose commitment over a period of 10,000 years would be 400 - 1 200 manrads/MW_e·year, i.e. a mathematical expectation of 0.08 - 0.2 cases of cancer over a 10,000 year period per MW_e·year. These two different values represent Swedish and American conditions respectively. However, a future community living directly on mill tailings piles is the worst conceivable case and the risk of this occurring cannot be other than speculative.

On an even longer time scale it is possible that the tailings will be spread by winds and erosion far beyond the original area In the extreme case, global distribution must be assumed. However, the extra irradiation to which man would be exposed would be very marginal and would also be relatively limited in time due to covering by other dust which is also spread by the winds. It can be shown, with reasonable assumptions, that in this case the natural background radiation from the ground would be increased by less than 0.0002 per cent and that the resultant collective dose commitment would be some tens of manrads/MW_e·year. It can therefore be ignored in comparison with the previous, equally speculative, example.

2.3 Dust hazards

Airborne dispersion of dust particles from the mill tailings involves a risk that airborne radioactivity will be inhaled by humans. Long-term measurements in the immediate vicinity (about 100 metres) of non-stabilized piles of mill tailings in the USA (1) showed an average concentration of about 3 per cent of the maximum permitted concentration for members of the public. If the airborne radioactivity had been in the form of insoluble dust particles, this 3 per cent corresponds to a lung dose of not more than 45 mrem/year. Due to deposition of the airborne particles, the concentrations in the air, and thus the radiation doses, will decrease rapidly with distance. The radiation doses to persons in the locality will therefore be much less than 45 mrem/year. The collective dose commitment in the locality can be estimated to be less than one manrad per year, thus giving a mathematical expectation of lung cancer of less than 10^{-4} per year for 10 000 persons. It cannot be estimated how long this would continue but on a purely hypothetical basis the mathematical expectation would be less than 10 cases of lung cancer during a period of 10,000 years. The mill tailings in the example above correspond to about 20.000 MW_e·y produced energy. The collective dose commitment for critical tissues in the lung will therefore be less than 0.5 manrad/MW_e·y.

2.4 Radon

The problem which has attracted most attention and which is most realistic in connection with the mill tailings piles is that of radon leakage. Radon is formed on the radioactive decay of radium-226 Both radium and its precursor thorium-230 are present in approximately the same quantities in the mill tailings as in the original uranium ore and their half-lives are very long (83,000 years for thorium-230). Although it is technically feasible to remove the radium and thorium, up to now this has not been regarded as a practical possibil ity due to the concomitant costs and the new problems which such a measure would involve.

The radon leakage from a pile of mill tailings is the result of a number of factors: the radium content of the tailings and their radon emitting capacity, the radon diffusion properties of the radon in the tailings, the area and thickness of the pile and its covering etc. The radon leakage is usually given in picocuries per m^2·sec (pCi/m^2·s) and it can vary from 1 - 4 pCi/m^2·s (Ranstad) to 500 pCi/m^2·s (USA) (2). These values apply to dry uncovered piles of tailings. If the tailings have a high water content the radon leakage is considerably reduced, to 1/10 or less. If the piles are covered with moraine and topsoil the radon leakage is also reduced. 0.5 - 1 metre can give a reduction to half, five metres to a tenth or less. At the experimental installation at Ranstad, a reduction to one thousandth has been obtained by covering with bentonite, with 1 metre of moraine and then with 30 cm of topsoil. Covering methods can therefore give extremely low radon leakage - sometimes even lower than that from the surrounding ground.

If it is assumed that the tailings piles loose their coverings after a very long period of time due to the effects of wind and erosion, the radon leakage reverts to the value without covering. The future consequences of this can be estimated from values for the radon leakage per $m^2 \cdot sec$ and how many m^2 of tailings are formed in order to produce uranium for 1 $MW_e \cdot$year. This latter value depends on the uranium content of the uranium ore and on the thickness of the tailings pile. If a typical value for American tailings piles is used 8 $m^2/MW_e \cdot$year (2), the result obtained is 44 manrads/$MW_e \cdot$year calculated over 10,000 years. For Ranstad it is estimated that for one of the planning alternatives the tailings piles will have an area of about 25 $m^2/MW_e \cdot$year. If the radon leakage is assumed to be 10 pCi/$m^2 \cdot s$ the resultant value is 3 manrads/$MW_e \cdot$year calculated over 10,000 years. The mathematical expectation of the number of lung cancer cases per $MW_e \cdot$year is then about 0.01 for the American conditions and about 0.001 for Ranstad over a period of 10,000 years.

In the hypothetical case in which the tailings are also spread outside the original tailings area, the effective area of the pile is increased, as is therefore the radon leakage. However, there are a number of limiting factors. Often only a fraction of the radon formed has any physical possibility of escaping from the particle in which it is formed. The value of this emanation factor varies from 1 - 2 per cent (Ranstad) to 20 - 25 per cent (USA). This means that even if all the tailings were laid out in a thin layer, not more than 1 - 25 per cent of the radon formed would be able to leak out into the environment. Another limiting factor is the containment of the dispersed tailings in other dust which is dispersed and spread on the ground. This results in the radon leakage being less over a long time scale after dispersion than when the tailings lay collected in piles without covering. The resultant radon leakage and radiation doses after dispersion of the tailings is therefore not considered in this connection.

2.5 Water

The environmental impact of releases in water may be of significance only for the local area and population. Leakage of uranium, thorium and radium may increase the concentration of these nuclides in fish and the consumption of fish may be the most important pathway to the population.

As uranium, thorium and radium are natural radioactive nuclides normally found in ground water and in lake water, the increase of the concentration in fish is not expected to be higher than the increase of the concentration in the water. By large dilution of the leakage from the tailings in ground water and in the lake the increase of the concentration in the water is expected to be moderate. However, the chemical composition of the leakage may be a factor of significance as regards the uptake in fish.

There are not many data on environmental consequences of leakage of tailings and they are by the reasons given above of specific, local nature. The experiences from Ranstad are very limited, but there is no indication that the leakage will be a serious radiological problem. However, and this is a general remark, because of the very long-time perspective of the environmental problems of tailings, it is seriously recommended that the environmental consequences of leakage to water will be carefully studied and analyzed.

3. CONCLUSION

The environmental impact of tailings from mining and milling of uranium has been discussed and estimated. The results are summarized in the table below. The radiological consequences have been calculated for a period of 10,000 years per an energy production of 1.000 $MW_e \cdot y$. Even if these environmental impacts can be considered to be low they are found to be much higher than corresponding environmental impacts of the mining and milling operations.

Table I

Sources	Mathematical expectation of number of cancers per 1.000 $MW_e \cdot y$ over 10,000 years
External radiation in case of settlement on uncovered tailings	80 - 200
Dust spread from the tailings:	
external radiation	< 10
inhalation	< 0.1
Radon from the tailings:	
covered	0
uncovered	1 - 10

References

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