

RESEARCH ON THE REMOVAL OF RADIUM FROM URANIUM EFFLUENT BY AIR-AERATION HYDRATED MANGANESE HYDROXIDE ADSORPTION

JIANGUO ZHANG, CHEN SHAOQING, QI JING
Chinese National Nuclear Corporation,
Beijing Research Institute of Chemical Engineering & Metallurgy,
Beijing, China

Abstract. In the acidic leaching uranium process, pyrolusite or manganese oxide (MnO_2) powder is often used as an oxidizer. In the processed effluent, manganese ion present as a contaminant in addition to U, Ra, Th, As, Zn, Cu, F, SO_4^{2-} , etc. Manganese ion content is about 100~200 mg/l in effluent. In this case, a new process technique can be developed to treat the effluent using the Mn^{2+} present in the effluent. The approach is as follows: The effluent is neutralized by lime milk to pH about 11. As a result, most contaminants are precipitated to meet the uranium effluent discharge standards (U, Th, Mn, SO_4^{2-} etc.), but radium is still present in the effluent. In this process, manganese ion forms manganese hydroxide $Mn(OH)_2$. The manganese hydroxide is easily to oxide to form $MnO(OH)_2$ by air aeration. This hydrated manganese hydroxide complex can then be used to adsorb radium in effluent. The experiments show: (1) Effluent pH, manganese concentration in effluent, and aeration strength and time etc. influence the radium removal efficiency. Under the test conditions, when manganese in effluent is between 100~300 mg/l, and pH is over 10.5, radium can be reduced to lower 1.11 Bq/l in the processed effluent. Higher contents of impurity elements such as aluminum, silicon and magnesium in the effluent affect the removal efficiency; (2) Under the experimental conditions, the lime precipitation air-aeration formed hydrated manganese hydroxide complex sludge is stable. There is no obvious release of radium from the adsorbed hydrated manganese hydroxide complex sludge; (3) The current experiments show that hydrated manganese hydroxide complex sludge has a very good re-adsorption ability for removal of radium from uranium effluent. Some experimental parameters have been measured.

Keywords: Uranium, Radium, Uranium effluent, Aeration, Hydrated manganese hydroxide, Adsorption

1. INTRODUCTION

A significant quantity of uranium effluent can be produced during uranium mining and milling operations. The natural radionuclide radium is a normal element existing in uranium effluent. It can have a great influence on the environment. The content of radium in effluent depends on the processed uranium ore grade and the processing technology. Generally, higher contents of radium always exist in association with higher grades of uranium ore. As environmental awareness increase and more stringent environmental protection requirements develop, the demand for rigid industrial effluent discharge standards increases. So the removal of the radium is an important step in uranium effluent process treatment because radium is a main radionuclide in uranium effluent. The discharge standards for effluents in the uranium industry to the environment in China are shown in Table 1.

TABLE I. THE DISCHARGE STANDARD OF THE LIQUID EFFLUENT FROM URANIUM INDUSTRY [1]

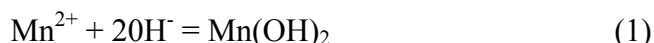
| Element | U | Th | Ra ²²⁶ | Pb | Hg | Cd | Cr | As | Cu | Zn | Mo | Ni | F | pH |
|----------------|------|-----|-------------------|-----|------|-----|------|-----|-----|-----|-----|-----|----|---------|
| Standard, mg/l | 0.05 | 0.1 | 1.11 | 0.1 | 0.05 | 0.1 | 0.05 | 0.5 | 0.1 | 1.0 | 0.5 | 0.5 | 10 | 6.5-8.5 |
| | | | Bq/l | | | | | | | | | | | |

There are many methods [2] that can be employed to remove radium from uranium mining and milling effluent. The normal methods used include: 1) barium chloride precipitation; 2) barite adsorption; and 3) pyrolusite removal of radium. In the barium precipitation process, good results for removal of radium can be obtained only when some sulfate ion exists in the effluent. The precipitated barium sulfate has poor deposition properties. So, large deposit cells are needed. Barite adsorption is one of the classical methods to remove radium, but there is no

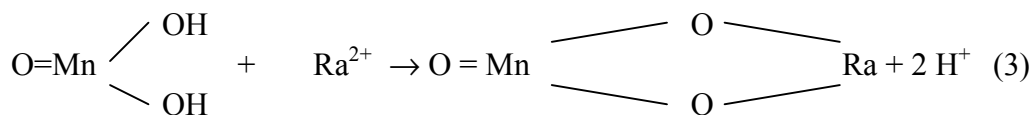
proper method to treat the adsorbed radium barite. Pyrolusite adsorption to remove radium is one of the economic methods to remove radium and the adsorbed pyrolusite can be recycled back to the leach process as an oxidizer. But different kinds of pyrolusite have significantly different adsorption properties. So, selection of an appropriate pyrolusite source is needed. In addition, activated sawdust, man-made zeolite, ion-exchange resin and precipitation-air aeration-hydrated manganese hydroxide adsorption [3] can be used to remove the radium from uranium effluent.

All uranium production countries have paid a lot attention to the treatment of uranium industrial liquid effluent. The discharge standard is very stringent. It is reported that there are about 26 countries with large and small scale of production capabilities for uranium. The discharge standards of liquid effluent have some little difference. In Canada, the maximum allowable level of ^{226}Ra is 0.37 Bq/l [4]. In China, the industrial discharge standard of ^{226}Ra in effluent is 1.1 Bq/l. The characteristics of uranium liquid effluents depend largely on the composition of the mined ore, local climate, hydrogeological regime, geographical location and most importantly the type of mining and processing techniques used economically exploit the deposit.

The mechanism of precipitation-air aeration-hydrated manganese hydroxide adsorption takes advantage of the Mn^{2+} ion in uranium effluent to treat the effluent, i.e. waste treatment is accomplished by the waste. Pyrolusite or manganese powder is used as oxidizer in most Chinese acidic leaching process uranium mills. So, uranium bearing effluent generally contains a great deal of Mn^{2+} ion. The processed tailing pulp is neutralized by lime milk to pH 7~8, then is discharged into a tailing pond. This effluent still contains radium, uranium, fluoride and manganese ions etc. Manganese ion content is about 100~200 mg/l. By further adjusting the effluent pH value, manganese ion reaction occurs as shown in equation (1) to form a hydroxide manganese deposit. This deposit is easily oxidized to form hydrated manganese hydroxide as shown by equation (2).



Previous research reports show that this hydrated manganese hydroxide has much better adsorption radium efficiency in alkaline medium than natural pyrolusite (5). The adsorption mechanism for radium by hydrated manganese dioxide is shown in equation (3):



As a potential method to treat the uranium effluent to remove radium, the experimental conditions about the formation hydrated manganese hydroxide complex by lime precipitation air-aeration is done and hydrated manganese hydroxide complex is used to adsorb radium in effluent simultaneously. Under the experimental conditions, lime precipitation air-aeration formed hydrated manganese hydroxide complex sludge is stable. There is no obvious release of radium from the adsorbed hydrated manganese hydroxide complex sludge. Also, hydrated manganese hydroxide complex sludge has a very good re-adsorption ability to remove radium from uranium effluent. Real acidic radium bearing effluent samples were from the Lantan mill plant. The study was carried out on the lime precipitation and air aeration method to determine

the process conditions and sludge stability. Certain achievements were made and some problems were found. The real effluent samples contain certain amount of aluminum, silica and magnesium ions, and the process efficiency for radium is not as good as reported by Cheng Shian [5]. It was found that when Al, Si, Mg contents are higher in liquid effluent, longer times are needed for clarification (about 7~8 days) or two steps are needed to process the effluent. First effluent pH is adjusted to 8 by lime milk, and Al, Si, and Mg are formed and removed. The second step is taking the supernatant liquid to pH 10.5~11, then air aeration for about 30 minutes to oxidize $Mn(OH)_2$ deposit to form $MnO(OH)_2$ and remove radium by adsorption.

In the experiments, the adsorbed radium sludge was examined and analyzed regularly for six months. The results indicate that the adsorbed radium sludge is stable. Also, the lime precipitation air-aeration formed hydrated manganese hydroxide complex sludge has a very good re-adsorption ability for removal of radium from uranium effluent.

2. EXPERIMENTS

Instrument and equipment

- 1) Acidity meter pH s - 3c
- 2) Air compressor Z - 0025/6
- 3) Aeration cell
- 4) 2000 ml cylinder
- 5) Adsorption column

Chemicals

| | |
|-------------------|----------------------|
| CaO | C.P (Chemical grade) |
| MnSO ₄ | A.R (Reagent grade) |
| Compressed air | |
| NaOH | A.R |

Air aeration operation

According to the processed effluent volume, 2000 ml cylinder or aeration cells are used for air aeration operation. Aeration strength is over 0.05 l/cm² min.

The composition of effluent is shown in Table 2

TABLE II. THE COMPOSITION OF EFFLUENT

| | | | |
|---------|-------|------------------------------------|------|
| U mg/I | 5.8 | F mg/l | 40 |
| Th mg/I | 1.7 | SO ₄ ²⁻ mg/l | 1560 |
| As mg/I | 1.0 | Ca ²⁺ mg/I | 300 |
| Ra Bq/l | 31 | Al ³⁺ mg/I | 90 |
| Cd mg/I | <0.02 | SiO ₂ mg/I | 80 |
| Cr mg/I | 0.05 | COD mg/I | 102 |
| Mn mg/I | 41.0 | pH | 1.54 |

Because the manganese content in effluent is low, a quantity of manganese was added to guarantee the experiment ran smoothly.

3. RESULTS AND DISCUSSION

3.1. Experimental conditions on the formation of the hydrated manganese hydroxide sludge and simultaneous adsorption radium

3.1.1. Influence of pH on the adsorption of radium

As the pH increases with lime precipitation and air aeration process, the residual radium content in the effluent decreases. When pH is adjusted to over 10.5, the radium content in effluent can be reduced from 31 Bq/ to 1.11 Bq/l. This result meets the required discharge standard. The results are shown in Figure 1.

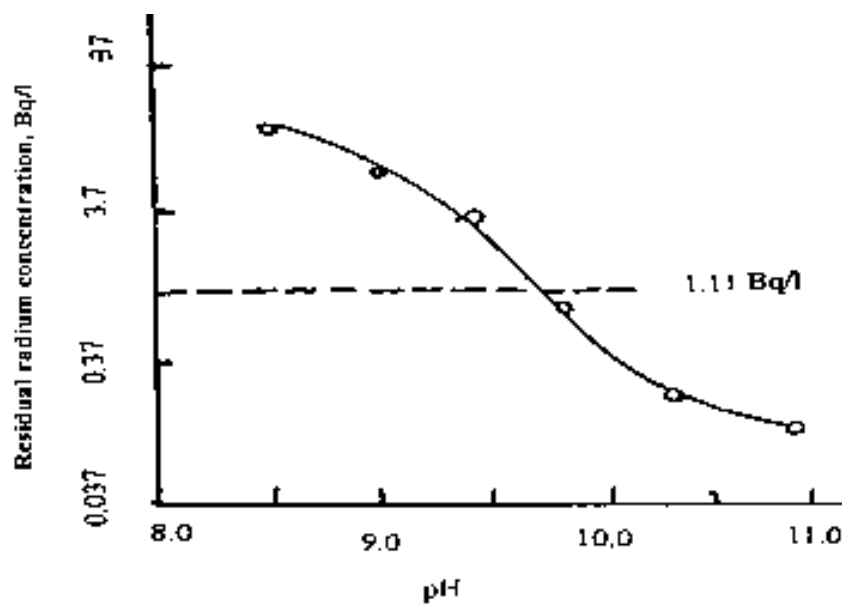
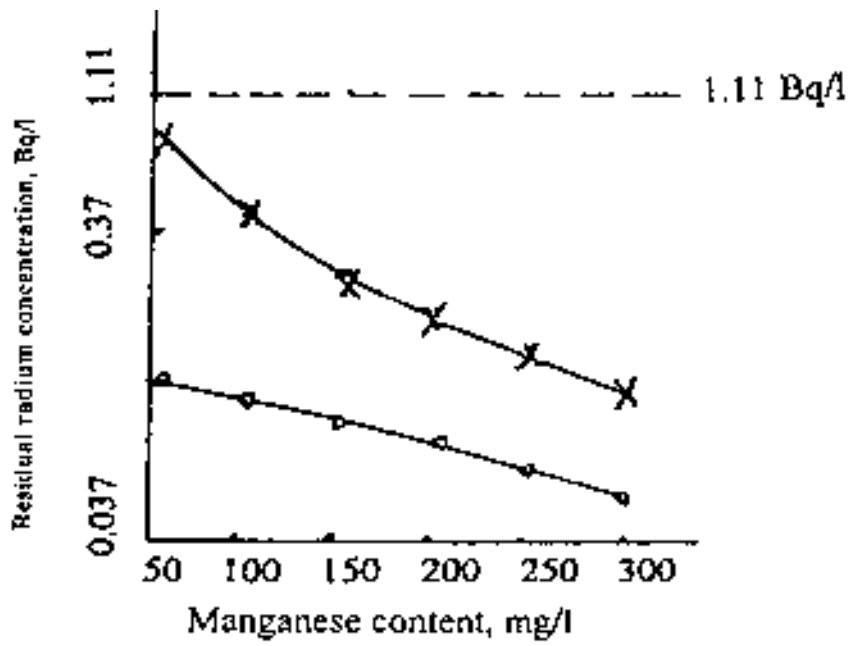


FIG. 1. pH influence on the removal of radium in the precipitation process. Manganese content 150 mg/l. Air aeration time 30 minutes.

3.1.2. Manganese content influence on the removal of radium

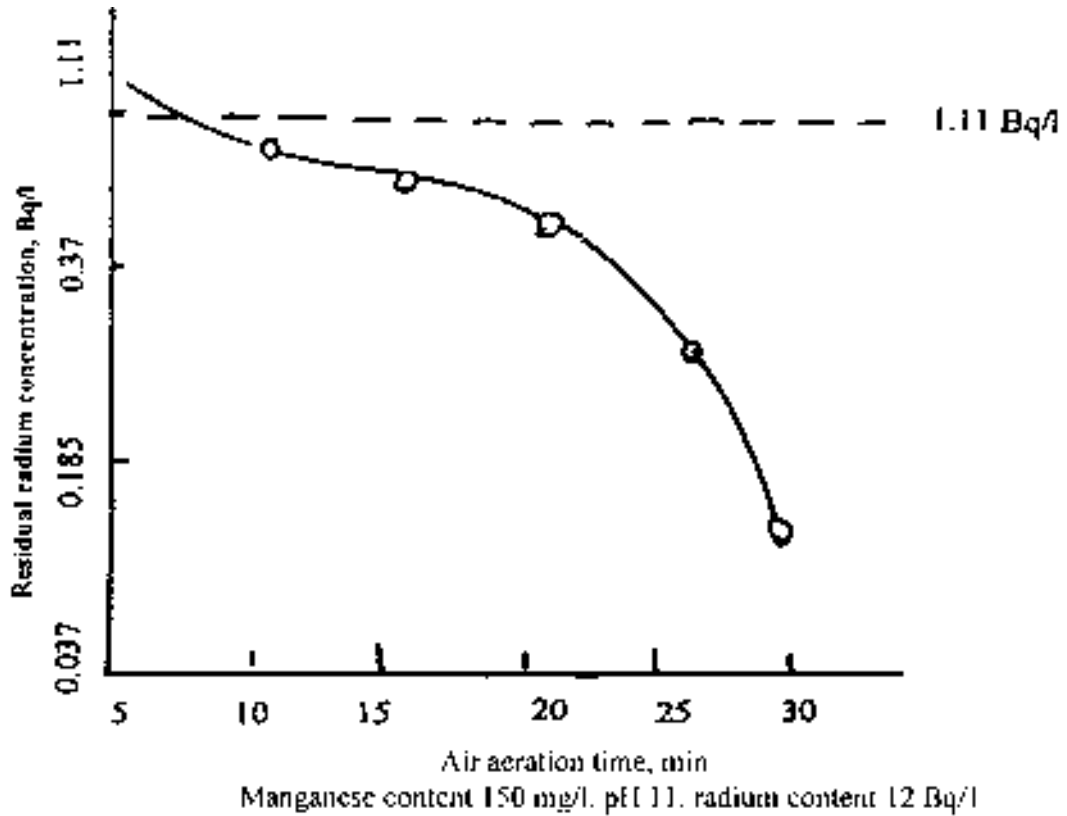
The effect of manganese content on the removal of radium is shown in Figure 2.

As shown by Figure 2, when manganese content in the effluent is increased, the residual radium content in effluent decreases. This is because the amount of hydrated manganese hydroxide formed increases with the amount of manganese present. Manganese content in the effluent should be increased with the increase in the original radium content of the effluent. When the original radium content in effluent is 3-40 Bq/l (typical) or 180 Bq/l (maximum), the manganese ions content in effluent must be over 100 mg/l or 200 mg/l respectively. In these cases, there are adequate amounts of manganese and the radium can be reduced as low as required. Good radium removal efficiency can be obtained with the increase of manganese ion in the effluent.



X-radium original content 33 Bq/l, o-radium original content 8 Bq/l. pH 11.
Aeration 30 minutes

FIG. 2. Influence of manganese content on the removal of radium.



Manganese content 150 mg/l. pH 11. radium content 12 Bq/l

FIG. 3. Air aeration time influence on the removal of radium.

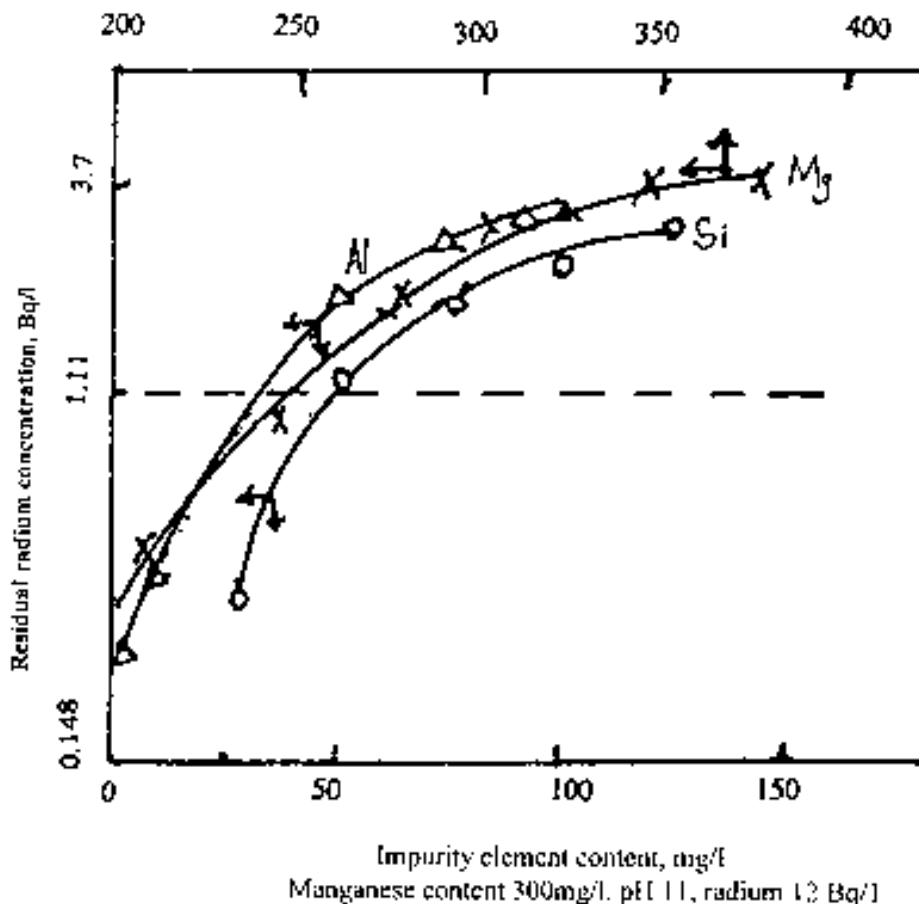


FIG. 4. Impurity elements influence on the removal of radium.

3.1.3. Aeration time

As the aeration time increases, the efficiency of radium removal is increased. This is because when other conditions are fixed, the longer aeration time provides enough oxygen from the air to oxidize the precipitated manganese hydroxide to form the large specific surface area of hydrated manganese hydroxide used to adsorb radium. That is, as aeration time increases, the production rate of hydrated manganese hydroxide is raised. For effluent containing radium between 3 and 40 Bq/l, manganese ion concentration of about 300 mg/l, with 30 minutes air aeration time can easily meet the required radium concentration. The results are shown in Figure 3.

3.1.4. Impurity elements of aluminum, silicon and magnesium effect on the removal of radium

In uranium industrial effluent, there is always some amount of aluminum, silicon and magnesium. Their contents depend on the property of the ore and process technology. The aluminum, silicon and magnesium in effluent have a great influence on the time precipitation-air aeration process to remove the radium from acidic uranium effluent. The results are shown in Figure 4.

Because the aluminum, silicon and magnesium contents in this effluent are relatively high, the results of removal of radium by lime precipitation-air aeration-hydrated manganese hydroxide adsorption are poor and can not meet the requirements at these high impurity levels. The clarification needs 8~9 days. In this case, two steps are employed to treat this kind of effluent.

First, effluent pH is adjusted to 8 to remove the aluminum, silicon and magnesium. Second, the clear solution is decanted and pH adjusted to 10.5~11 by lime milk, then, aerated by air. The removal result for impurities is shown in Table 3.

TABLE III. REMOVAL RESULTS FOR IMPURITIES ELEMENTS

| Element | U mg/l | Ra Bq/l | Mn ²⁺ mg/l | Al ³⁺ mg/l | SiO ₂ mg/l | Mg ²⁺ mg/l | pH |
|--------------------|-----------|------------|--------------------------|--------------------------|--------------------------|--------------------------|------|
| Original effluent | 5.8 | 31 | 300 | 90 | 80 | 91 | 1.54 |
| Processed effluent | 1.23 | 24 | 223 | 1.1 | 4.0 | 30 | 8 |

It can be seen from Table 3 that when the original effluent is adjusted to 8, aluminum, silicon are almost completely precipitated. And most of magnesium is deposited. The supernatant solution pH is then adjusted to 11.4. Air aeration takes 30 minutes. The uranium content in raffinate is reduced to below 0.05 mg/l, radium content is 0.2 Bq/l and other harmful elements can also meet discharge standards.

3.1.5. Clarification time

In the lime precipitation-air aeration process to treat the acidic uranium effluent, the longer the clarification time, the lower the radium in raffinate. Clarification time has relationship with original radium content and manganese ion content in effluent. When the content of aluminum, silicon and magnesium in effluent is low, 1~5 hours clarification time can meet the requirements. If aluminum, silicon and magnesium content are higher in effluent, much longer time for clarification is needed for precipitation of the radium to required levels. Due to the aluminum, silicon and magnesium levels existing in effluent in the lime precipitation-air aeration process, some very fine particles or gel-type solution is formed, so longer time is needed to conglomerate large particles for settling.

3.2. Experiment on the stability of hydrated manganese hydroxide complex sludge adsorption

3.2.1. Re-dissolving experiment

- 1) Taking one litre of effluent with radium content of 62 Bq/l, 300 mg/l manganese ion is added as MnCl₂ type salt. The effluent pH is adjusted to 11.1 by 10% w/w lime milk, then air aeration takes 30 minutes. After 40 minutes clarification time, U, Th, Ra and F etc elements in the supernatant liquid are analyzed. Then this liquid continues to be contacted with the deposited sludge, being stirred periodically. Analysis of radium and other elements are carried out regularly to see if there is a redissolution problem. The results are shown in Table 4.
- 2) Taking 1.6 litre of effluent with radium content of 62 Bq/l, 300 mg/l manganese is added as MnSO₄ type salt. The effluent pH is adjusted to 11.93 by 10% w/w lime milk, then air aeration takes 30 minutes. The deposit shows very dark brown. Measurement of radium etc. taken regularly. The results are shown in Table 5.
- 3) Re-dissolving the sludge by water

TABLE IV. THE REDISSOLUTION RESULTS OF RADIUM FROM DEPOSITED SLUDGE

| | Ra Bq/l | U mg/l | Th mg/l | F mg/l | pH |
|-----------|------------|-----------|------------|-----------|-------|
| 40 minute | 8.5 | < 0.05 | <0.025 | 4.5 | 11.1 |
| 9 day | 1.5 | | | | 11.1 |
| 12 day | 0.8 | | | | 11.06 |
| 25 day | 0.5 | | | | 10.56 |
| 32 day | 0.2 | | | | 9.57 |
| 44 day | 0.1 | | | | 8.65 |
| 60 day | 0.02 | | | | 7.60 |
| 90 day | 0.03 | | | | 7.70 |
| 120 day | 0.04 | | | | 7.64 |
| 150 day | 0.02 | | | | 7.65 |
| 185 day | 0.06 | <0.05 | <0.025 | 3.0 | 7.65 |

TABLE V. THE REDISSOLUTION RESULTS OF RADIUM FROM DEPOSITED SLUDGE

| | Ra Bq/l | U mg/l | Th mg/l | F mg/l | pH |
|---------|------------|-----------|------------|-----------|-------|
| 1 day | 4.5 | < 0.05 | < 0.02 | 4.5 | 12.0 |
| 8 day | 1.2 | | | | 12.05 |
| 17 day | 0.2 | | | | 11.53 |
| 24 day | 0.3 | | | | 11.36 |
| 36 day | 0.03 | | | | 10.64 |
| 53 day | 0.04 | | | | 8.30 |
| 84 day | 0.05 | | | | 8.17 |
| 114 day | 0.03 | | | | 7.93 |
| 144 day | 0.03 | | | | 8.25 |
| 180 day | 0.06 | < 0.05 | < 0.01 | 2.75 | 7.80 |

Taking 200g of lime precipitation-air aeration-hydrated manganese hydroxide sludge, 2000 ml tap water is added to re-dissolve radium in sludge. The contact ratio of solid to liquid is 1:10. The results are shown in Table 6.

TABLE VI. THE REDISSOLUTION RESULTS OF RADIUM FROM DEPOSITED SLUDGE BY WATER

| | Ra Bq/l | U mg/l | Th mg/l | F mg/l | pH |
|---------|------------|-----------|------------|-----------|------|
| 5 day | trace | <0.05 | <0.01 | 0.5 | 8.05 |
| 25 day | 0.3 | | | | 9.40 |
| 55 day | 0.03 | | | | 9.33 |
| 85 day | 0.01 | | | | 9.34 |
| 115 day | 0.02 | | | | 8.96 |
| 150 day | 0.01 | <0.05 | <0.01 | 0.49 | 8.91 |

It can be seen from Tables 4, 5 and 6 that the radium adsorption on the sludge is stable. There is not much release of radium from the deposited sludge under the experimental conditions. This achievement is in agreement with the research results by I. Nirdosh et al., [6, 7]. It is reported that adsorption of radium on freshly precipitated hydrous oxides of Fe, Mn, Zr, and Ti are investigated at pH 1 and 10. Radium removal was found to be highly sensitive to the

solution pH and all oxides effectively absorbed Ra at higher pH. However, significant radium adsorption was observed only on manganese dioxide. Desorption of Ra from the oxides was found to be difficult in alkaline solutions of EDTA.

The pH of the solution decreases with lime. It becomes nearly neutral. This is because the effluent adsorbed CO₂ from air because the alkali solution contacted with air for a long time. This is a benefit for the lime precipitation-air aeration process. If the processed effluent by lime precipitation-air aeration is not directly discharged to the natural environment, the effluent does not need to be re-neutralized by sulfuric acid. This effluent can be stored in the tailings dam for some time and the pH can reach the neutral condition.

3.2.2. Re-leaching the radium from adsorbed hydrated manganese hydroxide

To further study the stability of the adsorbed radium hydrated manganese hydroxide, the re-leaching of radium from adsorbed hydrated manganese hydroxide is studied with carbonate and sulfate. The results are shown in Tables 7 and 8.

TABLE VII. RE-LEACHING OF RADIUM BY SODIUM SULFATE. SOLID LIQUID RATIO 1:5, LEACHING TIME 24 HOURS, INTERMITTENTLY STIRRING

| | | | | | |
|---|-----|-----|------|------|------|
| So ₄ ²⁻ , concentration ppm | 200 | 500 | 1000 | 1500 | 2000 |
| Ra, Bq/l in leached liquor | 0.1 | 0.2 | 0.1 | 0.2 | 0.3 |

TABLE VIII. RE-LEACHING OF RADIUM BY AMMONIUM CARBONATE. SOLID LIQUID RATIO 1:5, LEACHING TIME 24 HOURS, INTERMITTENTLY STIRRING

| | | | | | |
|---|-----|-----|------|------|------|
| CO ₃ ²⁻ , concentration ppm | 200 | 500 | 1000 | 1500 | 2000 |
| Ra, Bq/l in leached liquor | 0.1 | 0.2 | 0.1 | 0.2 | 0.3 |

It can be seen from Tables 7 and 8 that the adsorbed radium hydrated manganese hydroxide is stable under the experiment conditions.

3.3. Re-adsorption of radium from uranium effluent by lime precipitation air-aeration formed hydrated manganese hydroxide complex sludge

In parts two and three, the experiments show that lime precipitation air-aeration formed hydrated manganese hydroxide complex sludge has the ability to remove radium from the uranium effluent and maintain the adsorbed radium. For the application of this technique in the industrial practice, re-adsorption experiment on the radium by lime precipitation air-aeration formed hydrated manganese hydroxide complex sludge was done in this part and the normal uranium tailing sludge (with little manganese) was used as a reference.

3.3.1. Effect of effluent pH on the adsorption of radium by the hydrated manganese hydroxide complex

Two kinds of adsorbent are used: hydrated manganese hydroxide complex and the normal uranium tailing sludge. A 0.10 gram sample of each adsorbent is contacted with 100 ml of uranium effluent with variable pH for adsorption time of 24 hours. Then, separation was carried out and radium in the tailing effluent analyzed. The results are listed in Table 9.

TABLE IX. THE EFFECT OF EFFLUENT pH ON THE ADSORPTION OF RADIUM BY THE HYDRATED MANGANESE

| Effluent pH | Adsorbent | Radium content in effluent | Radium in adsorbed liquor | Absorbed liquor pH | Radium removal efficiency |
|-------------|--------------------------------------|----------------------------|---------------------------|--------------------|---------------------------|
| 1.45 | hydrated manganese hydroxide complex | 35 Bq/l | 0.18 Bq/l | 7.90 | 99.5% |
| | normal uranium tailing sludge | | 11 Bq/l | 1.78 | 68.6% |
| 7.0 | hydrated manganese hydroxide complex | 9.0 Bq/l | 0.3 Bq/l | 9.95 | 96.7% |
| | normal uranium tailing sludge | | 1.2 Bq/l | 7.45 | 86.7% |
| 9.42 | hydrated manganese hydroxide complex | 4.0 Bq/l | 0.16 Bq/l | 10.17 | 96 % |
| | normal uranium tailing sludge | | 1.1 Bq/l | 8.04 | 72.5% |

3.3.2. Contact time influence on the radium adsorption

One gram of hydrated manganese hydroxide complex and normal uranium tailing sludge were respectively contacted with 100 ml, pH=1.45, Ra=35 Bq/l, U=11.7 mg/l original effluent at different adsorption times to study the contact time influence on the radium adsorption process. The experimental results are shown in Tables 10 and 11.

TABLE X. CONTACT TIME INFLUENCE ON THE RADIUM ADSORPTION BY HYDRATED MANGANESE HYDROXIDE COMPLEX

| No. | Contact time, minutes | Adsorbed effluent pH | U in adsorbed effluent, mg/l | Ra in adsorbed effluent, Bq/l | U removal efficiency | Ra removal efficiency |
|-----|-----------------------|----------------------|------------------------------|-------------------------------|----------------------|-----------------------|
| M1 | 5 | 2.56 | 11.7 | 25 | --- | 28.57% |
| M2 | 10 | 2.95 | 11.2 | 20 | 4.3% | 42.86% |
| M3 | 15 | 2.64 | 11.6 | 17 | 0.1% | 51.43% |
| M4 | 30 | 2.58 | 11.4 | 19 | 2.5% | 45.71% |
| M5 | 60 | 3.14 | 10.1 | 16 | 13.7% | 54.29% |
| M6 | 120 | 5.24 | 0.9 | 1.6 | 92.3% | 95.43% |
| M7 | 300 | 6.06 | 0.9 | 0.74 | 92.3% | 97.89% |

TABLE XI. CONTACT TIME INFLUENCE ON THE RADIUM ADSORPTION BY NORMAL URANIUM TAILING SLUDGE

| No. | Contact time, minutes | Adsorbed effluent pH | U in adsorbed effluent, mg/l | Ra in adsorbed effluent, Bq/l | U removal efficiency | Ra removal efficiency |
|-----|-----------------------|----------------------|------------------------------|-------------------------------|----------------------|-----------------------|
| W1 | 5 | 1.31 | 10.5 | 30 | 10.25% | 14.28% |
| W2 | 10 | 1.30 | 10.8 | 35 | 7.69% | --- |
| W3 | 15 | 1.29 | 10.3 | 34 | 11.96% | 2.86% |
| W4 | 30 | 1.29 | 10.3 | 32 | 11.96% | 8.57% |
| W5 | 60 | 1.29 | 10.3 | 33 | 11.96% | 5.71% |
| W6 | 120 | 1.29 | 10.3 | 35 | 11.96% | --- |
| W7 | 300 | 1.23 | 10.3 | 29 | 11.96% | 17.14% |

3.3.3. Influence of original effluent pH and contact time on radium adsorption by hydrated manganese hydroxide complex

pH value 1.45 uranium effluent was adjusted to 7.44 by sodium hydroxide. The uranium content in adjusted solution was below 1 mg/l, Ra content was 7.7 Bq/l. This solution (100 ml) was contacted with 1 gram hydrated manganese hydroxide complex at different contact times. The uranium content and radium content in adsorbed tailing effluent was analyzed to evaluate the effluent pH and contact time influence on radium adsorption. The results are shown in Table 12.

TABLE XII. THE INFLUENCE OF ORIGINAL EFFLUENT pH AND CONTACT TIME ON RADIUM ADSORPTION BY HYDRATED MANGANESE HYDROXIDE COMPLEX

| No. | Contact | Adsorbed effluent pH | U in adsorbed effluent, mg/l | Ra in adsorbed effluent, Bq/l | Ra removal efficiency |
|-----|---------|----------------------|------------------------------|-------------------------------|-----------------------|
| M11 | 5 | 8.71 | 0.5 | 0.66 | 91.43% |
| M12 | 10 | 8.56 | 0.6 | 0.95 | 87.66% |
| M13 | 15 | 8.72 | 0.6 | 0.38 | 95.06% |
| M14 | 30 | 8.71 | 0.4 | 0.85 | 88.96% |
| M15 | 60 | 8.70 | 0.9 | 0.42 | 94.55% |

3.3.4. Column adsorption

Column diameter was 14.6 mm, 15 grain hydrated manganese hydroxide complex was compacted in this column. The packed column height was 120 mm, volume was 20 ml. Packed density was 0.75 g/cm³. Inlet pH of the effluent was about 7, radium was about 9.0 Bq/l. Residence time was 30 minutes. The experiment took three months. The breakthrough point is defined as 1.11 Bq/l. The column operation results are listed in Table 13.

In about three months operation, 26000ml uranium effluent was processed with a discharge standard of radium as 1.11 Bq/l. About 22000ml of the discharged uranium effluent had radium content below 0.4 Bq/l. A total of 228 Bq radium was adsorbed by 15 gram hydrated manganese hydroxide complex sludge. The manganese content in the sludge was 5.6%. So, manganese content in 15 gram hydrated manganese hydroxide complex sludge is 0.84 gram. Thus, the process ability of manganese on radium adsorption is 271 Bq/g.

In general, as the experiments above show, pH has a great influence on the adsorption of radium by hydrated manganese hydroxide complex. The adsorption pH choice can be between 6.5 and 9. At this effluent pH, the adsorption residence time can be 5 minutes. Also, the hydrated manganese hydroxide complex shows good adsorption capacity for radium removal in uranium influent. The capacity at breakthrough point 1.11 Bq/l is 271 Bq/g manganese. The normal uranium tailing sludge has some radium adsorption capacity. But compared with the hydrated manganese hydroxide complex, this adsorption is small. Also, the radium in outlet effluent (the adsorbed effluent) is over the industrial discharge standards.

TABLE XIII. COLUMN ADSORPTION RADIUM RESULT BY HYDRATED MANGANESE HYDROXIDE COMPLEX

| No | Outlet volume, ml | pH of outlet effluent | Total volume, ml | BV number | Ra content in outlet effluent, Bq/l |
|----|-------------------|-----------------------|------------------|-----------|-------------------------------------|
| 1 | 50 | 8.53 | 50 | 2.5 | 0.19 |
| 2 | 50 | 8.56 | 100 | 5 | 0.09 |
| 3 | 50 | 8.53 | 150 | 7.5 | 0.08 |
| 4 | 69 | 8.30 | 333 | 16.65 | 0.06 |
| 5 | 68 | 8.44 | 469 | 23.45 | 0.04 |
| 6 | 51 | 8.43 | 679 | 33.95 | 0.15 |
| 7 | 50 | 8.21 | 830 | 41.5 | 0.15 |
| 8 | 50 | 8.13 | 982 | 49.1 | 0.10 |
| 9 | 50 | 8.17 | 1133 | 56.65 | 0.09 |
| 10 | 50 | 8.19 | 1233 | 61.65 | 0.12 |
| 11 | 50 | 8.13 | 1385 | 69.25 | 0.10 |
| 12 | 50 | 8.07 | 1537 | 76.85 | 0.12 |
| 13 | 50 | 7.00 | 1689 | 84.45 | 0.14 |
| 14 | 51 | 8.11 | 1842 | 92.1 | 0.16 |
| 15 | 50 | 8.19 | 2043 | 102.15 | 0.20 |
| 16 | 51 | 7.94 | 2247 | 112.35 | 0.08 |
| 17 | 51 | 8.04 | 2451 | 122.55 | 0.27 |
| 18 | 51 | 8.01 | 2655 | 132.75 | 0.15 |
| 19 | 50 | 8.09 | 2859 | 142.95 | 0.13 |
| 20 | 51 | 8.01 | 3012 | 150.6 | 0.18 |
| 21 | 51 | 7.97 | 3215 | 160.75 | 0.17 |
| 22 | 50 | 8.07 | 3417 | 170.85 | 0.15 |
| 23 | 75 | 7.90 | 3593 | 179.65 | 0.15 |
| 24 | 95 | 8.04 | 3688 | 184.4 | 0.16 |
| 25 | 50 | 7.91 | 3950 | 197.5 | 0.16 |
| 26 | 50 | 7.97 | 4150 | 207.5 | 0.14 |
| 27 | 50 | 8.03 | 4350 | 217.5 | 0.12 |
| 28 | 70 | 8.13 | 4616 | 230.8 | 0.14 |
| 29 | 50 | 8.10 | 4841 | 242.05 | 0.15 |
| 30 | 50 | 8.11 | 4991 | 249.55 | 0.15 |
| 31 | 60 | 7.76 | 5261 | 263 | 0.16 |
| 32 | 53 | 7.99 | 5524 | 276.2 | 0.17 |
| 33 | 55 | 7.99 | 5735 | 286.95 | 0.19 |
| 34 | 55 | 7.42 | 5998 | 299.9 | 0.17 |
| 35 | 54 | 7.90 | 6215 | 310.75 | 0.21 |
| 36 | 54 | 7.94 | 6429 | 321.45 | 0.16 |
| 37 | 57 | 7.96 | 6599 | 330 | 0.13 |
| 38 | 58 | 7.00 | 6862 | 343.1 | 0.16 |
| 39 | 53 | 7.92 | 7075 | 353.75 | 0.18 |
| 40 | 53 | 7.94 | 7286 | 364.3 | 0.16 |
| 41 | 55 | 7.93 | 7448 | 372.4 | 0.17 |
| 42 | 55 | 8.01 | 7553 | 377.65 | 0.18 |
| 43 | 54 | 7.90 | 8091 | 404.55 | 0.18 |
| 44 | 54 | 7.96 | 8461 | 423 | 0.20 |
| 45 | 54 | 7.90 | 8728 | 463.4 | 0.23 |
| 46 | 54 | 8.15 | 9155 | 457.75 | 0.21 |
| 47 | 54 | 7.98 | 9585 | 479.25 | 0.18 |
| 48 | 54 | 7.97 | 9905 | 495.25 | 0.19 |
| 49 | 54 | 7.82 | 10289 | 514.45 | 0.17 |

TABLE XIII. (cont.)

| | | | | | |
|----|-----|------|-------|---------|------|
| 50 | 54 | 7.93 | 10659 | 532.95 | 0.18 |
| 51 | 52 | 7.86 | 10921 | 546 | 0.18 |
| 52 | 45 | 7.90 | 11228 | 561.4 | 0.19 |
| 53 | 53 | 7.53 | 11603 | 580.15 | 0.17 |
| 54 | 53 | 7.53 | 11976 | 598.8 | 0.18 |
| 55 | 53 | 7.35 | 12346 | 617.3 | 0.17 |
| 56 | 52 | 7.49 | 12612 | 630.6 | 0.18 |
| 57 | 53 | 7.45 | 12980 | 649 | 0.17 |
| 58 | 52 | 7.48 | 13347 | 667.35 | 0.20 |
| 59 | 52 | 7.46 | 13712 | 685.6 | 0.18 |
| 60 | 52 | 7.42 | 14076 | 703.8 | 0.18 |
| 61 | 52 | 7.50 | 14440 | 722 | 0.19 |
| 62 | 45 | 7.60 | 14680 | 734 | 0.19 |
| 63 | 44 | 8.43 | 15415 | 770.75 | 0.34 |
| 64 | 75 | 8.43 | 15835 | 791.75 | 0.31 |
| 65 | 45 | 7.67 | 16230 | 811.5 | 0.29 |
| 66 | 52 | 7.93 | 16947 | 847.35 | 0.32 |
| 67 | 155 | 7.82 | 17612 | 880.6 | 0.35 |
| 68 | 52 | 7.94 | 18329 | 916.45 | 0.38 |
| 69 | 51 | 7.92 | 19045 | 952.25 | 0.33 |
| 70 | 52 | 7.84 | 19757 | 987.85 | 0.34 |
| 71 | 51 | 7.86 | 20416 | 1020.8 | 0.37 |
| 72 | 51 | 7.82 | 21122 | 1065.1 | 0.40 |
| 73 | 50 | 7.84 | 21827 | 1091.35 | 0.40 |
| 74 | 150 | 7.86 | 22527 | 1126.35 | 0.43 |
| 75 | 52 | 6.65 | 23407 | 1170.35 | 0.52 |
| 76 | 55 | 6.52 | 24112 | 1205.6 | 0.81 |
| 77 | 77 | 6.42 | 24674 | 1233.7 | 1.06 |
| 78 | 70 | 6.53 | 24969 | 1248.45 | 0.88 |
| 79 | 70 | 7.00 | 25294 | 1264.7 | 1.08 |

4. CONCLUSIONS

The advantage of lime precipitation-air aeration-hydrated manganese hydroxide adsorption to process uranium effluent is application the waste ions in effluent to treat the effluent. This is beneficial for the environmental protection. And it is also an effective method to process the uranium effluent. The following points can be drawn from research and experiments:

1. The effluent pH of the air aeration to produce hydrated manganese hydroxide to adsorb radium and remove other harmful elements must be adjusted to about 11 by lime milk. Manganese ion concentration in effluent between 100~300 mg/l can meet the requirement to remove the radium. The contents of manganese depend on the amount of radium in original effluent and other impurities.
2. The longer the air aeration time, the better result for radium removal because as aeration time increases, production rate of hydrated manganese hydroxide is raised. Normally 30 minutes of air aeration time can meet the requirement.
3. Impurity elements of aluminum, silicon, and magnesium have a great effect on the lime precipitation-air aeration-hydrated manganese hydroxide to process acidic uranium

effluent. This is a big disadvantage. If higher contents of these elements exist in effluent, longer time for clarification is needed or two steps are required. First step to remove the impurity from the effluent by lime adjusting pH to 8, second step to remove radium by air aeration at pH about 11.

4. The longer clarification time benefits the effluent process. The clarification time is related to impurity levels in the effluent. For low concentrations of aluminum, silicon and magnesium in effluent, 1~5 hours can meet the requirement. For higher concentrations, the clarification time may be as long as 8~9 days.
5. Under the experimental conditions, the radium adsorption by hydrated manganese hydroxide sludge produced with lime precipitation-air aeration process is stable. There is no obvious release of radium from the sludge. If the processed alkaline effluent is stored in a tailings dam, there is no need to neutralize the effluent. It will be neutralized by adsorbing CO₂ from the air. This will save operation and reagent cost.
6. pH has a great influence on the adsorption of radium by the hydrated manganese hydroxide complex. The adsorption pH choice can be between 6.5 and 9. At this effluent pH, the adsorption residence time can be 5 minutes. Also, the hydrated manganese hydroxide complex shows good re-adsorption ability at radium removal in uranium influent.

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EFFLUENTS FROM A WASTE ROCK DEPOSIT OF A FORMER URANIUM MINE IN SAXONY/GERMANY — MASS FLOW BALANCE OF WATER AND DISSOLVED SOLIDS

D. BIEHLER

Colenco Power Engineering AG,
Liestal, Switzerland

Abstract. Soon after uranium mining had ceased in eastern Germany in 1990, work for remediation of several mining sites began. The Wismut GmbH, owner of the Mine of Dresden-Gittersee's waste rock dump, introduced the concept of reducing the impact to the environment via water and air paths by implementing a multi-layer soil cover. The deposit consists mainly of waste rock (clastic sediments of Döhlener Becken, deep metamorphic rocks) but also of low-grade ore (U-rich coal) and tailing materials. At the time when remediation started, the effluents completely infiltrated the underground. Because of previous surface exfiltration activities, they were already known to be very rich in dissolved solids, especially in sulphate and uranium. As demanded by the state authorities, the owner funded a vast hydrogeological study of the site. In testing the efficiency of surface sealing, the study indicated a mass flow balance of water and dissolved solids for the current situation, and predicted emissions into the water path which would occur after realisation of the proposed soil cover. The field investigation program consisted of:

- measurements of flow, of concentrations of dissolved solids (esp. U and Ra-226) and of contents of environmental isotopes in precipitation, surface runoff, seepage water and groundwater in the current condition of the dump
- the study of waste rock material (geochemistry, mineralogy)
- waste rock material elution tests
- underground investigation by drilling boreholes up to 270 m in depth

The resulting data allowed for:

- a hydrogeological conceptual model of the site
- a consistent mass flow balance for the current condition of the dump
- a prediction of concentrations in groundwater resulting after the realisation of a soil cover

The predictions show that the concentrations of dissolved solids in the contaminated groundwater would be significantly decreased. Furthermore it would be possible to reach the standards for drinking water with respect to uranium content. Based on the presented study the realisation of the proposed surface cover can be recommended.

1. INTRODUCTION

The area south of Dresden, Saxony was a coal mining district for decades. Partial natural enrichment of the coal with uranium wasn't discovered until the 1950's. For some time both coal and uranium were mined simultaneously. Starting in the end of the sixties, only uranium mining continued. Mining then was fully operated by the former Soviet-German mining company SDAG Wismut and lasted over a period of another 20 years. In conjunction with the reunification of Western and Eastern Germany into one state in 1989, uranium mining was halted in the entire country including at Dresden-Gittersee. Close-down operations already started in 1990. Responsible for the closing-down of this mine is Wismut GmbH, a company fully owned by the federal government.

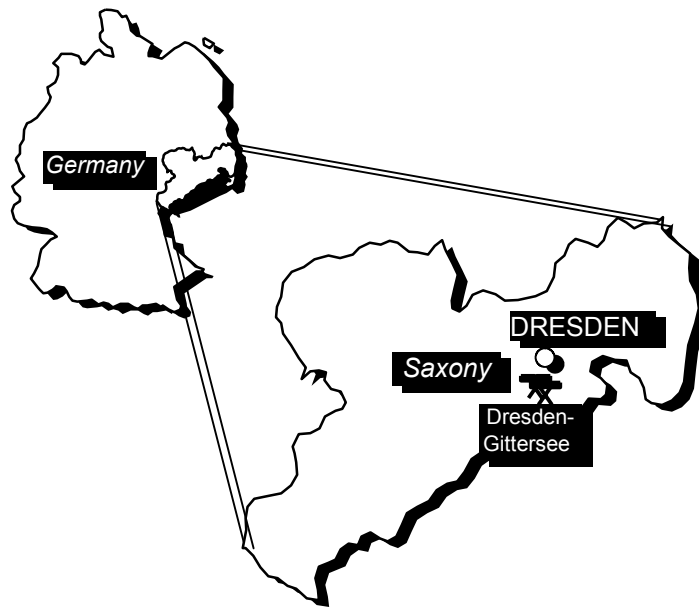


FIG. 1. Location of the mining site.

2. SITUATION AND PROBLEM

Several surficial deposits of mine waste exist in the area as remnants from the period of uranium mining. One of those, the dump of shafts 1 and 2, mainly consisting of waste rock is located in the immediate vicinity of the city of Dresden in a district named Gittersee (Fig. 1). In order to minimize the impact on the environment potentially caused by the release of contaminated effluents and the exhalation of radon, Wismut GmbH plans to implement a multi-layer soil cover on the dump. One important target of remediation are deep wells in the vicinity of the dump, which were used for drinking water supply at the time.

The project required the approval of the state authorities responsible for radiation protection. As a basis for its decisions, the authority demanded a hydrogeological study for the site, including a mass flow balance of water and dissolved solids in the current state of the dump, as well as predictions of effects due to the realisation of the project.

Using available documents and data, Colenco worked out a concept for the study which was based on field investigations and semi-quantitative analyses of data. The field investigation program consisted of:

- measurements of flow and piezometric head, determination of concentrations of dissolved solids (esp. U_{tot} and Ra-226) and of contents of environmental isotopes in precipitation, surface runoff, effluents and groundwater;
- the study of waste rock material (geochemistry, mineralogy);
- performing waste rock material elution tests;
- underground investigation by drilling boreholes up to 270 m in depth.

The data analysis included:

- validation and interpretation of data
 - development of a conceptual hydrogeological model
 - evaluation of mass flow
 - prediction of concentrations by simple analytical calculations
- The work was done by a group consisting of Office Schmassmann (at that time a part of Colenco-Holinger AG), Wismut GmbH and BEAK Consultants GmbH.

3. SITE CHARACTERISATION

General information

Some general data on the dump site are given in Table 1.

TABLE I. GENERAL DATA OF DUMP (AFTER WISMUT 1994)

| Waste rock dump Dresden-Gittersee, Saxony/Germany (state 1993) | | |
|--|----------------|------------|
| in operation | | since 1950 |
| Altitude | | |
| - top (plateau) | m.a.s.l. | 275 |
| - lowermost point | m.a.s.l. | 230 |
| area (at bottom) | m ² | 104'900 |
| height of waste rock pile | | |
| - maximum | m | 30 |
| - average | m | 8 |
| Volume | m ³ | 832'000 |
| slope gradient | | 1:3 |
| Content | | |
| - waste rock: clastic sediments of Döhlen Basin and deep metamorphic rocks | | |
| - low-grade ore: U-rich coal | | |
| - tailing materials | | |

Geology and hydrogeology

As for the geological setting, the coal deposit is part of the Döhlen basin tectono-sedimentary structure which is filled with terrestrial clastic sediments of Lower Permian age, the so called "Rotliegendes".

The dump rests mostly on a thin layer of weathered rock and some soil, covering the underlying bedrock of the Lower Interstratified Formation. This Lower Interstratified Formation is a member of the "Rotliegendes" and consists of an inhomogeneous series of clastic sediments. Merely the uppermost part of the dump site is located on a thin sandstone formation of Cretaceous age.

The Lower Interstratified Formation is underlain by the Upper Breccious Conglomerate Formation, the Banded Silty Arkose Formation, the Lower Breccious Conglomerate Formation and the Niederhäslich-Schweinsdorfer Formation, all of which belong to the Lower Permian "Rotliegendes". As the names of its formations reveal, the "Rotliegendes" is composed of layers of conglomerates, sandstones and siltstones.

The Kaitzbach valley resembles a Quaternary gravel deposit.

From exposed rock faces and drilling observations one may roughly outline the hydrostratigraphy. It may be divided into coarse grained units like sandstones and conglomerates which function as aquifers and fine grained strata which represent aquicludes. Because the porosity of sandstones and conglomerates is very low, the permeability of the aquifers is controlled mainly by open fractures.

A detailed picture of the hydrostratigraphy evolved as the conceptual model of the local hydrogeology was developed. It consists of a complex system of aquifers with varying degrees of hydraulic communication (Fig. 2). At the top are the Upper Cretaceous sandstones, an unconfined aquifer with a freely fluctuating groundwater table. They are followed by the clastics of the inhomogeneous Lower Interstratified Formation. The available data is insufficient to derive an exact picture of its internal structure. It is conceptualized as lenses of coarser material, i.e. local aquifers possibly with perched water tables, embedded in a less conductive matrix. Nevertheless, the Lower Interstratified Formation as a whole is considered as one of the three main aquifers of the "Rotliegendes", the other two being the Upper Breccious Conglomerate Formation and the Lower Breccious Conglomerate Formation.

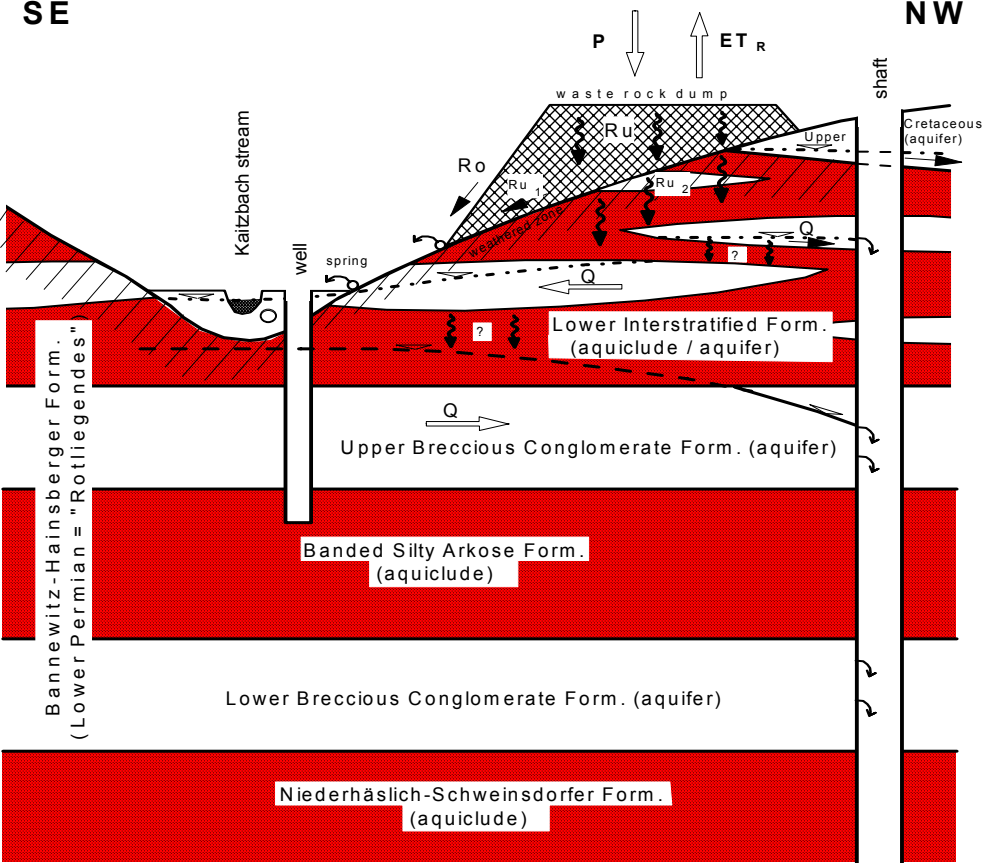


FIG. 2. Conceptual hydrogeological model.

The discharge of the Lower Interstratified Formation concentrates on one main spring, the Rotliegend-Quelle situated besides the Kaizbach valley, with an average discharge rate of 1 L/s. One of the recharge areas of the Lower Breccious Conglomerate Formation aquifer is assumed to be located in the area of surficial outcrops in the Kaizbach valley downstream of the dump whereas discharge occurs in the shafts of the former mine. For this reason

groundwater flow in the two systems is of opposite direction. Several deep wells situated along the Kaitzbach stream use groundwater from the Lower Breccious Conglomerate Formation aquifer – one of them for drinking water supply.

Chemical analyses have shown significant contamination by effluents of the dump in the Upper Cretaceous sandstone aquifer and in the aquifers of the Lower Interstratified Formation but only weak influence on the deep system of the Lower Breccious Conglomerate Formation used by wells (see table 2).

TABLE II. SELECTED DATA OF OBSERVATION PERIOD 1995/96

| | Sample Location | date | Cl mg/L | SO ₄ mg/L | U mg/L | Ra-226 mBq/L | |
|---------------------|---------------------------------|--------------------------------------|----------|----------------------|--------|--------------|---------|
| precipitation | Collector Cunnersdorf | average 1995/96 | <1.08 | 6.09 | n.a. | n.a. | |
| Effluents | monitoring well UK10 | 31.10.95 | 241 | 1970 | 0.56 | 5.8±0.8 | |
| Groundwater | regional background | effluent spring SQ2 Kaitzbach spring | 03.11.95 | 129 | 1590 | 3.4 | 81±7 |
| | Upper Cretaceous | monitoring well GWMS 6508a/96 | 31.10.95 | 39 | 131 | 0.005 | 2.3±0.5 |
| | Lower Interstratified Formation | monitoring well Rotliegend spring | 28.10.96 | 78 | 436 | 0.040 | 114±7 |
| | Quaternary of Kaitzbach valley | monitoring well P42 | 31.10.95 | 183 | 1560 | 0.38 | 5.2±0.8 |
| | Lower Breccious Conglomerate | monitoring well GWMS 6501/95 | 1.11.95 | 50 | 162 | 0.059 | 6.4±0.8 |
| | | | 42 | 105 | 0.014 | 5.5±0.6 | |
| n.a. – not analysed | | | | | | | |

4. ANALYSIS OF MASS FLOW

Methodology

The analysis of the mass flow was comprised of three steps:

1. generation of a mass flow balance consistent with current conditions at the dump
2. correction of mass flow balance for long-term effects
3. prediction of effects of sealing the dump with a soil cover

Database

A mass flow balance was generated for the current conditions at the dump site with its two components, the water balance and the distribution of dissolved solids (Table 3).

The water balance was investigated by BEAK based on measurements of precipitation and surface runoff, results of quantitative model calculations for the evaporation rates, and subsurface runoff rates for the dump site as determined from a climatic water balance for the

current conditions at the dump site. Groundwater flow rates were determined from piezometric observations.

The dissolved solids content was determined for samples of meteoric water (precipitation) collected at Cunnersdorf, samples of surface runoff collected at different points of the waste rock pile, samples of effluents collected from a monitoring well and two effluent springs, as well as for formation water samples drawn from the various aquifers. A selection of four chemical constituents representative of the overall dissolved solids content is provided in Table 3. It is worth noting that the effluents show a neutral pH of 6.3 – 7.2.

TABLE III. DATABASE FOR MASS BALANCE

| | | flow rate* | Cl | SO ₄ | U | Ra-226 | |
|-------------|-----------------------|------------|------|-----------------|-------|--------|------|
| | | L/s | mg/L | mg/L | mg/L | mBq/L | |
| Dump | recharge | 1.62 | <1.1 | 6.1 | 0 | 0 | |
| | surficial runoff | 0.19 | 10 | 287 | 0.05 | 14.2 | |
| | subsurface runoff | 0.12 | 289 | 2364 | 2.5 | 100 | |
| Groundwater | Upper | <i>in</i> | 38 | 122 | 0.004 | 2.3 | |
| | Cretaceous | <i>out</i> | 0.30 | 78 | 436 | 0.04 | |
| | Lower Interstratified | <i>in</i> | | 52 | 176 | <0.002 | 14.1 |
| | Formation | <i>out</i> | 0.90 | 153 | 1297 | 0.31 | 4.4 |
| | Quaternary of | <i>in</i> | | 38 | 122 | 0.004 | 2.3 |
| | Kaitzbach valley | <i>out</i> | 0.15 | 49 | 170 | 0.07 | 5.3 |
| | Lower Breccious | <i>in</i> | | 41 | 98 | 0.02 | 5.7 |
| | Conglomerate | <i>out</i> | 0.50 | 60 | 276 | 0.03 | 17.6 |

* part of total flow that is potentially affected by effluents

Semi-quantitative analysis

A semi-quantitative analysis, i.e. without the use of numerical models, was conducted to study the long-term behaviour for cases with and without soil cover. The following assumptions were applied in the analysis:

- the quality of the effluent is stable,
- in the long term the groundwater flow increases by a factor about equal to the factor of increase in precipitation,
- the effluent outflow is reduced by a factor equal to the reduction of permeability of the cover material.

It is supposed that there will be no change of geochemical milieu (especially no acidification) in the long term so that the quality of the effluent may be considered stable.

The comparison of measured precipitation rates to long-term monitoring data from surrounding stations in the area led to the long-term rate of 56 mm/a (9% of P) or 0,19 L/s. It is assumed that the application of the soil cover reduces the overall permeability of the waste rock pile by at least two orders of magnitude. The subsurface runoff is therefore reduced at

least to 1/100 of the current rate. In turn, the infiltration rate is reduced to 0.56 mm/a or 0,002 L/s.

It was then attempted to calculate predictive values for contaminant concentrations in the groundwater for the situation after the soil cover has been applied by adjusting the mass flow data and background data accordingly.

5. RESULTS

The observed concentrations of sulphate and chloride in groundwater may not be explained by the currently observed subsurface runoff concentrations of dump. It is presumed that there is another source of these indicative contaminants located below the dump site (see Fig. 3). A possible explanation would be a residual, historic contamination with mine water which is stored and released from micropores in the bedrock. In contrast, the uranium balance shows an equilibrium, i.e. the calculated freight rates in groundwater are equal to those in the effluent (Fig. 3).

The radium balance shows a depletion in the underground, in other words the freight rates are lower in the groundwater than in the effluent.

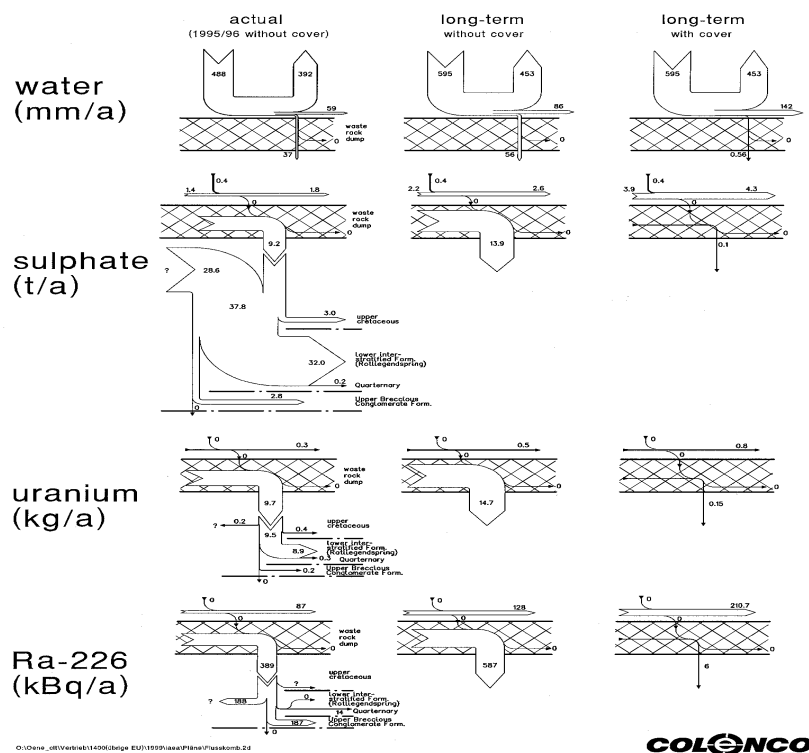


FIG. 3. Results of mass flow analysis for different states of dump (note: masses derived from groundwater background are not shown!).

In summary it becomes apparent that a reduction of emission rates out of the waste rock dump has a significant effect in the case of radium and uranium but not in the case of chlorine and sulphate (see Fig. 4). The goal is to reach the standard maximum allowable concentrations for drinking water for uranium already over a mid-term period for the water sources currently most affected. Radium has dropped already below these maximum allowable concentrations (Fig. 4).

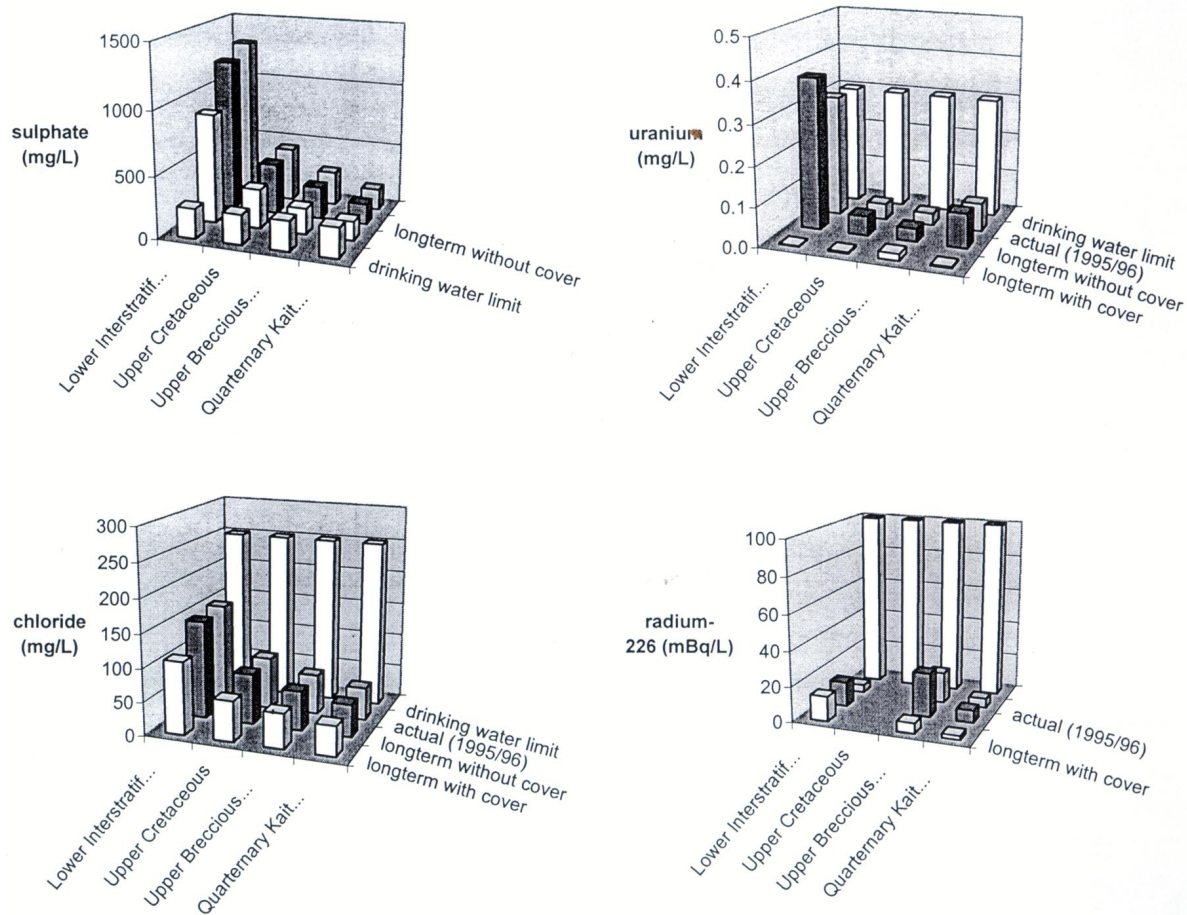


FIG. 4. Predicted concentrations of contaminants in groundwater.

6. CONCLUSIONS

Based on the results of this study the implementation of the proposed surface cover may be recommended. The expected effects include a significant reduction of uranium emissions into the groundwater. Less notable reductions in the concentrations in the groundwater are expected for sulphate and chloride as these are influenced by a secondary source in the bedrock in addition to the effluent emissions from the waste rock dump. On the other hand dump derived Radium seems to be fixed in the bedrock in significant amounts.

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