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URANIUM TAILINGS BASIN CLOSURE CASE STUDIES

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ABSTRACT

Uranium ore was processed by the Soviet-German Wismut company until 1990 at two main sites. At Crossen 74 million tonnes of ore were processed and the principal basin was constructed using upstream raising to a maximum dam height of about 60 m. At Seelingstädt the four basins hold tailings from 110 million tonnes of ore. There are dams with a maximum height of over 55 m and the greatest depth of the tailings fines is about 70 m.

For the German Federal Ministry of the Environment, Nature Conservation and Reactor Safety (BMU) Brenk Systemplanung investigated and evaluated options for the closure of the principal basin at Crossen and then carried out a similar study for the four Seelingstädt basins. The objective in each case was to identify the optimum type of closure.

The probabilistic comparison of the options involved estimates of costs and of risk levels. The risks included health effects from radiation dose and from the ingestion of arsenic, as well as the fatalities if a dam were to collapse. Health risk was ascribed a damage cost on the basis of society's willingness to pay to prevent a reduction of life expectancy. The occurrence of defects and the consequences of a possibly ineffective institutional control were also incorporated.

The results of Monte Carlo simulations confirmed a dry cover as the optimum closure method, with the cheaper wet cover excluded due to the radiation effects in the event of loss of the water cover and the severe consequences if a dam failure were to occur.

SITE HISTORY

Immediately after World War II uranium mining was begun in East Germany in the states of Thuringia and Saxony (Nelson, et al.1994; Mager and Goldammer, 1997). Latterly, before German reunification, mining and processing was carried out by the Soviet-German Wismut company. In this paper studies of the closure of the tailings basins at the two principal Wismut mill sites are discussed.

At Crossen (Saxony) between 1952 and 1989 were processed 74 million tonnes of ore and the principal basin at Helmsdorf was constructed for alkali leached tailings using upstream raising to a maximum dam height of about 60 m. At Seelingstädt (Thuringia) between 1960 and 1989 four tailings basins containing the residues from 110 million tonnes of ore were developed in worked-out open-pits. There are peripheral dams with a maximum height of over 55 m, some constructed as an upstream raise, and the maximum depth of the tailings fines is about 70 m. Two of the basins contain tailings from acid leaching of the ore, with the associated potential problem of acid generation.

OPTIMIZATION OF THE CLOSURE

As for all such sites the challenge is to identify an optimum physical closure method. For the Wismut sites this requirement for optimization is actually contained within the relevant regulations, although the procedure to be followed in identifying the optimum is not specified (Anon., 1984). The requirement

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that the radiological detriment for the population should be as low as achievable with expenditure which is acceptable to society is the ALARA principle as adopted by ICRP. The regulations also define maximum permitted radiation doses.

The conceptual spectrum of closure options ranges from doing almost nothing, if this is acceptable in terms of dose levels, to very expensive options. Low cost closure options are often associated with significant environmental detriment and the increased costs of the other kinds of solutions may have to be accepted as a way of reducing these impacts. The question which may be asked is how environmentally safe a solution a society should reasonably demand. As a concrete example; would the construction of an underground repository for the tailings be justified? In Figure 1 it is shown that we can conceive of a range of physical options with increasing cost associated with decrease in the environmental detriment. Which option is best? The studies described in this paper used estimates of the amount society is willing to pay to prevent specific environmental consequences to enable a direct comparison to be made with the other costs. The optimum was identified as the option with the lowest total costs.

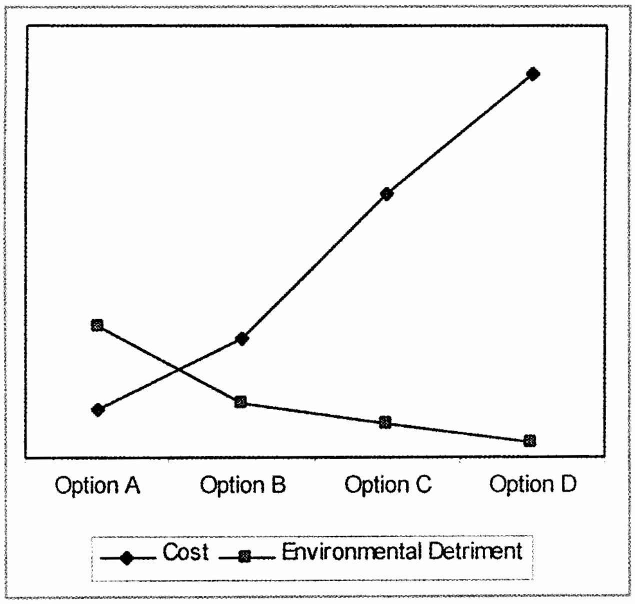

Figure 1.

THE STUDIES AND PERMITTING

Within the closure programme for the Wismut sites the German Federal Ministry of the Environment, Nature Conservation and Reactor Safety (BMU) has a supervisory role in connection with radiation protection. Permits for the closure work are the responsibility of the state (Thuringia or Saxony) within which the facility is located. Brenk Systemplanung carried out the studies described here for BMU, with the intention that the results would guide the preparation of applications and eventually the issue of permits. Interim results for the Crossen site were presented in 1995 (Goldammer, 1995).

DESCRIPTION OF THE CROSSEN SITE

The first of the studies was carried out for the over 200 ha Helmsdorf tailings basin at the Crossen mill site. The basin was formed by damming existing valleys, with the main dam located above the village of Oberrothenbach. Most of the dam construction for the basin was based on the upstream raise method. The basin is located on the Rotliegendes formation, which is generally of low permeability, but there are faults and also recent, more permeable, deposits in the valley bottoms.

The climatic conditions at Crossen are typical for central Europe with rainfall distributed throughout the year and a mean temperature of about 10°C. Older records indicate an average annual rainfall of about 745 mm (1921 – 1940), but there was an average of only 615 mm between 1980 and 1993. The estimated annual evaporation from a water surface is about 600 mm. The site is within the saxothuringian seismic zone. Recorded events indicate a 1000 year return period intensity at the site of about 6.4 MSK (Macroseismic scale). This is equivalent to a maximum ground acceleration of around 0.07 g.

At the time of the study seepage from the dams and the foundations was being collected and returned by pipeline to the mill site for treatment. This seepage contains arsenic in addition to the radionuclide contamination. In the basin area the exposed beach areas had been covered with inert material. This action was taken to reduce dusting.

DESCRIPTION OF THE SEELINGSTÄDT SITE

At Seelingstädt the four tailings basins were formed in two worked-out open-pits, in each case by constructing a separator dam across the pit. In each pair of basins one was used to dispose of the tailings from the acid leach circuit and the other for the alkali leach tailings. The total area of the tailings at Seelingstädt is almost 370 ha.

For the Trünzig basins the north dam was constructed from tailings by an upstream raise and the others with overburden material. For Culmitzsch all the outer dams were constructed with tipped overburden.

The open-pits which now contain the tailings were excavated in Permian strata. It is thought that in several of the basins there is a direct hydraulic connection to permeable sandstone strata. Beneath the Permian are Ordovician slates, which have relatively low permeability.

The meteorological conditions are generally similar to those at Crossen. The average precipitation recorded in the period 1981 to 1994 was 585 mm. Seelingstädt is also within the saxothuringian seismic zone but the conditions are more severe, with a 1000 year return period intensity at the site of about 7.9 MSK. This is equivalent to a maximum ground acceleration of around 0.22 g.

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At the time the study was carried out for the Seeingstädt basins the exposed tailings beaches had been covered with inert fill material to prevent dusting. The whole of Trünzig A had already been covered in this way.

CLOSURE OPTIONS CONSIDERED - CROSSEN

An evaluation of the existing situation at Crossen showed that action had to be taken. For one thing the physical situation was not sufficiently stable. The analysis of the main dam had shown that the risk of failure under earthquake loading was too great. With recycling of the seepage a rise in water level would occur, with adverse effects on dam stability. A further problem was that the radiation dose limits (maximum individual dose 1 mSv/a for a local resident) could not be met.

Options for relocation of the tailings were considered but these were excluded on qualitative grounds before the detailed evaluation was commenced. Complete underground disposal would require a new mine and would be so expensive that it would only need to be considered if all above ground options, including the in situ ones, were shown to be extremely expensive or inefficient. A search for possible locations for a new above ground repository revealed nothing which was suitable. If one had been found it would have been necessary to account for the costs of decommissioning the existing basin area.

On the basis of the radon and dust emission from the uncovered tailings it was clear that if they were to stay in place a cover would be required. Thus the acceptable in situ options were essentially various different types of cover. Two principal options are available; wet and dry covers.

With all wet options at least part of the tailings surface is permanently covered by water. Two extreme possibilities can be envisaged; the natural water level which is maintained without pumping collected seepage back into the basin, and a substantially higher managed water level covering all the tailings.

For dry options the final surface must be shaped to prevent the formation of a pond. Once again two extremes can be envisaged; a cover which achieves the minimum required reduction of radon emission, and a cover which reduces both radon emission and infiltration. With reduction of infiltration the effects on the water pathway can be limited.

The two wet cover and two dry cover options for the Helmsdorf basin are shown schematically in Figure 2 and their principal differentiating features are described below. In all options the dam slopes would be flattened, covered and vegetated. Collected seepage would be treated and either discharged to the river or returned to the basin.

Option 1 small pond

The water level in the basin would be lowered and then managed using a spillway through natural ground and other measures to ensure that the seepage line within the dams is low. Covers incorporating a drainage layer, a layer of fine-grained material to restrict radon emission and a layer enabling the establishment of vegetation would be constructed over the exposed tailings. A similar cover would be required over the exposed basin shoreline, but without the drainage layer where there are no tailings.

Option 2 large pond

The whole of the area within the dams would be covered with a minimum water depth of 1.5 m. In order to facilitate this about 5% of the tailings would be relocated from near the spigotting points to the deepest part of the basin. To stabilise the dams cut-off walls penetrating into the foundations would be constructed and wells with submersible pumps would be installed in the downstream shoulder to control porewater pressure temporarily in the event of leakage through the cut-off. At the dam crest a rip-rap system would be required to prevent erosion by wind-induced waves. For the control of the basin water level a spillway and other management measures would be required.

Option 3 dry cover with natural infiltration

The ponded water and water draining from the tailings during consolidation would be pumped out and treated before discharge to the river. Tailings surfaces would then be covered with a system incorporating a drainage layer, a fine-grained layer to restrict emission of radon and a layer allowing the establishment of vegetation. In exposed shore-line areas without any tailings the drainage layer would be omitted. The drainage from the surface of the covered basin would be via a channel constructed through natural ground adjacent to the lowest point on the tailings surface.

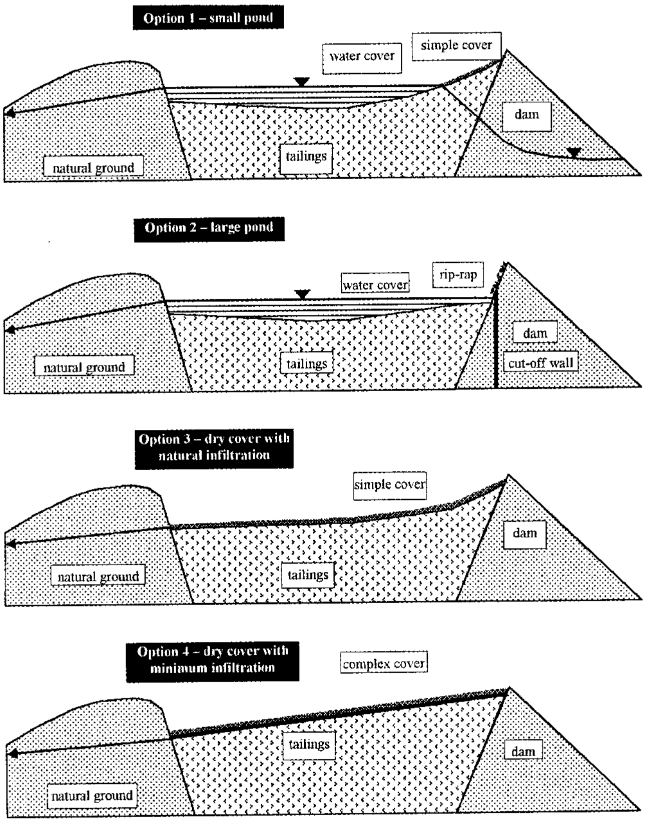

Figure 2.

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Option 4 dry cover with minimum infiltration

This option is similar to the previous one except that the covers, including those on the dams, would be designed to limit infiltration of precipitation and the cover would be profiled to ensure run-off. For this purpose additional material would have to be brought to the basin. Further measures to improve the performance of the cover system were assumed to be required. The objective would be to accelerate the consolidation of the tailings by pumping from sand zones and the use of vertical drains. Over the tailings and the dams the cover system would include instead of the fine-grained radon seal a clay sealing layer, a drain layer and a layer to protect against frost and store water for plant growth.

CLOSURE OPTIONS CONSIDERED – SEELINGSTÄDT

The options for the basins at Seelingstädt were derived directly from the preceding Crossen study, but some modifications resulted from the different conditions at the sites.

It was apparent from the water balance data that the two Culmitzsch basins and the Trünzig A basin had such high seepage losses that the size of the naturally maintained pond would be very small. This means that for these basins the option of a small pond (option 1) would be scarcely distinguishable from a dry cover with natural infiltration (option 3). In contrast, for Trünzig B an excess of water would result in a natural pond size similar to that assumed under option 2. The option of a small pond was thus not included in the detailed optimization study for Seelingstädt.

For the option of a dry cover with minimum infiltration no allowance was made at Seelingstädt for measures to accelerate the tailings consolidation process. The proposed temporary cover would significantly reduce the radon emission during the period until settlement had slowed enough for the final cover to be constructed. Thus no benefit would result from the acceleration measures.

INPUTS TO THE OPTIMIZATION

As most of the input factors have a significant associated uncertainty, especially those associated with projections of future behaviour of the system, the approach was taken of defining probability distributions for the parameters. These were frequently triangular distributions of the general form: lowest estimate – expected value – highest estimate. For some of the inputs common to all options additional sensitivity analyses were made to check the stability of the results of the optimization.

COMMON INPUTS

Optimization period

An important element in the evaluation of the various options is the period to be considered. It is clear that with consideration of a longer period both cumulative environmental effects and costs will tend to increase. There is also a greater chance that rare events such as earthquakes will occur which may, in turn, damage the closure system. In these studies the EPA guideline period of 1000 years for uranium tailings was adopted as the primary period on the basis that the objective was to investigate the long term performance of the available options (Federal Register, 1983). A subsidiary period of 200 years was also considered as within this period the estimates have a lower degree of uncertainty.

Institutional controls

A significant factor in the performance prediction for the closure systems is the effectiveness of the institutional controls. Effective active controls leading to early recognition and repair of a defect will normally result in a quite different outcome to that which occurs where the undetected defect triggers a chain of increasingly significant problems. Similarly the status of passive controls, such as planning restrictions, may have a significant influence on the probability of occurrence of intrusion scenarios. A probability distribution was ascribed to the likelihood that institutional controls had ceased to be effective. For each simulation case it was then decided on the basis of the selected probability whether control was effective or not. This result was then used in the calculations of the system responses. Failure of active institutional control occurred within the 1000 year period in about two thirds of the cases.

Occurrence and effects of defects

For each of the options the probability of occurrence of various kinds of defects was estimated. Examples are damage to the wave protection for a wet cover option or erosion of part of the cover for a dry system. The consequences of the defect were then estimated in terms of repair activity or, in the absence of institutional control, in terms of the risks for the population and the possibility of developing more serious defects. Damage to the wave protection could allow erosion of the dam crest and then a dam failure, with its high risks for the population and large clean-up costs. The chain of consequences resulting from erosion of part of the cover depends on the details of the cover construction. In a simple case there would either be repair activity or risk for the population resulting from the increase in radon emission.

Defect scenarios for Seelingstädt were based on those for Crossen, but those shown by that study to be of low significance for the decision were not considered in detail for Seelingstädt. Other changes resulted from the different site conditions. One example results from the expectation that without the pumping associated with effective institutional control the water level in three of the basins at Seelingstädt would drop. Thus dam failure scenarios resulting from ineffective institutional control and damage to the wave protection need not be considered.

Damage costs ascribed for health risks

Direct and cancer related health risks considered. Direct risks include, as an extreme case, those resulting from a dam failure and release of tailings. The risk of cancers results from

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radiation and, in the case of Crossen, also from ingestion of arsenic. For both types of risk it is possible to estimate for a population group a cumulative reduction of life expectancy. The damage cost ascribed in the studies for this cumulative reduction in life expectancy is based on the amount society is willing to pay to prevent it occurring. Recent publications indicate an average willingness to pay of about DM 200,000/a. Review of values used by ICRP for comparison of dose reduction and costs resulted in a similar figure.

ENVIRONMENTAL FACTORS

Air pathway

Radon emissions were estimated for each of the options and also for the case of exposure of the tailings following erosion of a dry cover or loss of the water cover. Using a radon dispersion model calibrated from the existing conditions predictions were made of the resulting collective dose. Exposed tailings were estimated to emit 10 to 20 times more radon than with a dry cover and about 200 times more than with a water cover.

Water pathway

The estimates for the water pathway of radioactive dose and for Crossen of risk from ingestion of arsenic were based on assumed residual concentrations in the treated water discharged into the local river system. It was assumed for the case of ineffective institutional control that untreated water would be discharged and also that water supply wells would be installed in contaminated zones.

RISKS

Conventional risks for the workers result from the physical closure operations. For the population there are also conventional risks for options requiring that material is imported to the site along public roads. A dam failure would present a large risk for the people living in the path of the outflowing water and tailings but should only occur when institutional control is ineffective.

COSTS

Investment costs

Investment costs were estimated for the physical closure work and also for the construction of a water treatment facility and for its operation during the closure process.

Operating and repair costs

Long term costs were estimated for water treatment and also for inspection, maintenance and repair of the closure systems. These were converted to net present values using an expected value of 3.5% for the discount rate.

IDENTIFICATION OF THE OPTIMUM

As discussed above, the optimum solution is that with the lowest total of environmental and other costs. The combination of the relevant factors was carried out using a Monte Carlo simulation. In this procedure the calculation of the target value, say total cost, is carried out many times, with new values of the input parameters chosen for each calculation based on their probability distributions. The result is a probability distribution of the target value. The identification of the optimum is then based on a comparison of the output distributions for the options.

RESULTS OF THE OPTIMIZATION

For Crossen the results showed that the infiltration minimising dry cover (option 4) was the best option in terms of both mean and extreme values. The higher initial investment provides more passive safety. This reduces both the chance of defects and the magnitude of their consequences - even when no maintenance is carried out. This is shown in Figure 3 where the effects of defects are compared in terms of cumulative probability distributions of total costs. For any percentile the wet cover effects are worse, even without considering a dam failure. Loss of the water cover and exposure of the tailings results in a high dose. The quantification of this difference for the 1000 year optimization period showed clearly that the higher investment cost is justified (Figure 4). It is only with the dry option that the occurrence of extremely high total cost outcomes can be excluded.

In Figure 5 the results are presented for the complete set of options considered in the study. In this alternative format the horizontal lines in the bars represent the 95, 90, 70, 50, 30, 10 and 5 percentile points.

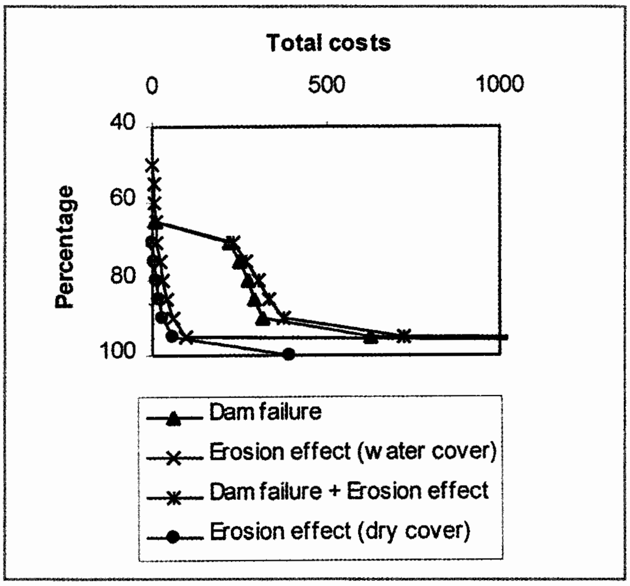

Figure 3.

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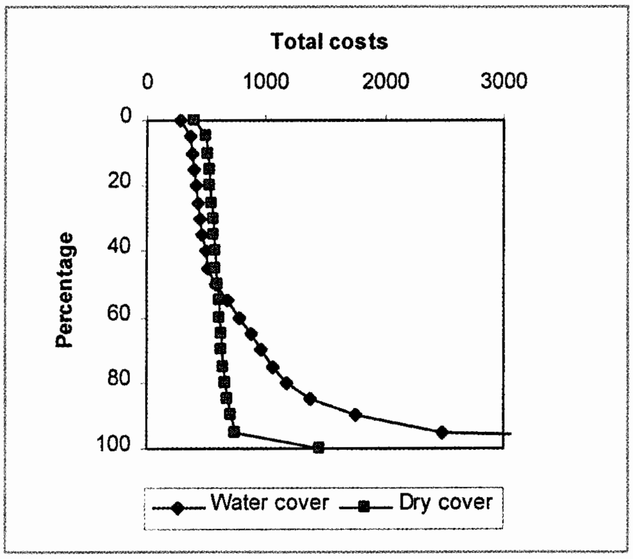

Figure 4.

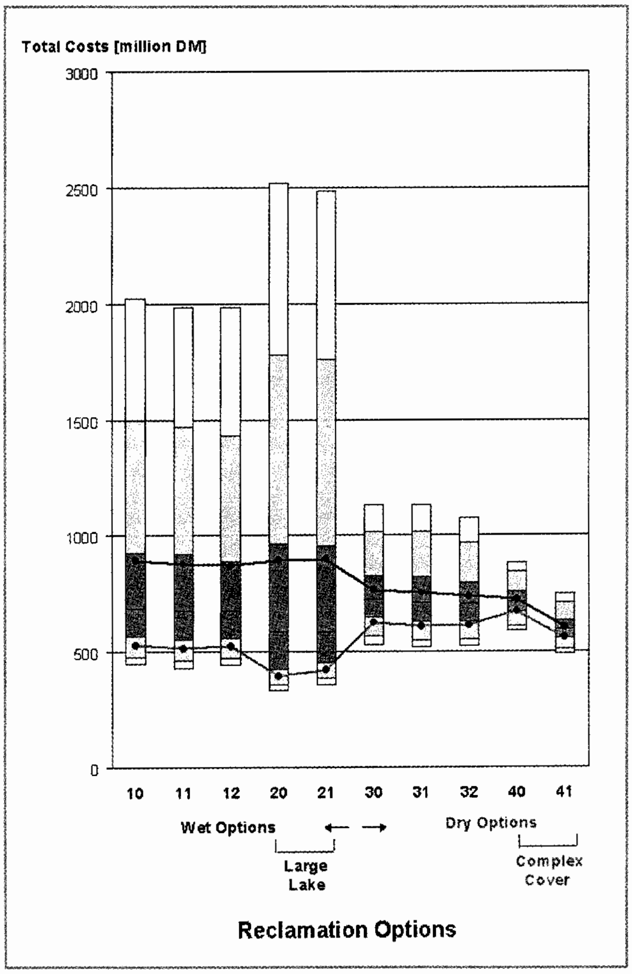

Figure 5.

The pattern of the simulation results for Seelingstädt were similar to those for Crossen, but the difference between the two types of dry cover was less distinct. As there were also some greater uncertainties, such as the long term geochemical behaviour of the basins containing tailings from acid leaching, the conclusion of the study was limited to the identification of a dry cover as the optimum for all of the basins.

CONCLUDING REMARKS

It is considered that the use of the approach described here resulted in valuable insight into the behaviour of the systems. This formal approach is being applied for the numerous secondary decisions required during the planning process after the fundamental choice of option has been made. Some aspects of the approach, and in particular its more recent extension to include a wider range of non-radiological risk, are still under discussion (Goldammer et, al., 1999).

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