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MANAGEMENT OF CURRENT AND CONTINGENT LIABILITY THROUGH MINE WASTE MANAGEMENT

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ABSTRACT

Mine waste represents the largest current and contingent environmental liability for the mining industry. This liability is, however, rarely recognized and its cost most frequently under estimated. The requirement exists for such recognition by both regulatory and financial institutions. The industry's need to avoid expensive and high profile environmental site remediation is also driving the advancement of this science. Methods of defining liability at mine sites for proposed, active and closed properties are reviewed in this paper. In addition, the management of mine waste to minimize liability is reviewed in the context of two mine sites, the Kennecott Ridgeway Mine and the Grouse Creek Mine, both in the USA. The approach to using "Design and Operation for Closure" and a review of the cost-benefit of such, are also presented.

INTRODUCTION

Mine waste represents the largest current and contingent environmental liability for the mining industry. This liability is related to the cost of environmental management and the closure and reclamation of the waste management facilities. The liability is, however, rarely recognized and its cost most frequently under estimated. The requirement exists for such recognition by running companies, regulatory and financial institutions. The industry's need to avoid expensive and high profile environmental site remediation is also driving the advancement of this science. Methods of defining liability at mine sites for proposed, active and closed properties require the adoption of specific procedures to develop a realistic liability evaluation.

The methods of management of mine waste facilities are central to a mine's ability to comply with environmental regulations and ultimately, the method and cost of closure and reclamation of a project. This paper outlines an approach to identifying contingent liability, methods of reducing such liability, and for prioritizing actions and expenditures. The objective of this approach is to institute, at a mine or corporate level, a process by which both environmental performance is improved and contingent liability reduced.

A five-step process can assist in achieving this objective. These steps are:

- Develop an Environmental Management System (EMS): Standards and Practices Document;
- Perform project reviews to establish current liabilities and relative performance of properties;

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- Evaluate the contingent liability of each property in terms of a Failure Modes Effects Analysis (FMEA);
- Evaluate the risk of incurring each contingent liability by applying risk analysis methods to the FMEA; and
- Evaluate all properties with a relative ranking system incorporating the performance, liability and risk associated with each property.

Intrinsic to this process is the "operation and design for closure" approach. The paper then provides the example of the Kennecott Ridgeway Mine at which this procedure and approach have been applied.

GENERAL DISCUSSION

The process for the evaluation and management of contingent liability is a little developed skill in the mining industry. Frequently, properties are evaluated in terms of their recent compliance history rather than their ability to position for future compliance and ultimately for closure. Normal practice is to develop a cost estimate for closure and reclamation for the purpose of bonding or providing financial assurance to regulatory agencies. The amount of the bond is initially calculated at the permit stage and is frequently not re-addressed in any detail until closure is imminent. The conceptual closure plans upon which the costs are based are subject to change due to actual operating conditions encountered. Budgeting for the management of changing conditions and for actual closure costs is intrinsic to recognizing and accounting for actual liability. To better define current liability, an operation and design for closure approach in which the underlying objectives for closure are established and operating decisions made in terms of achieving such objectives, can be adopted. In addition, the opportunity to focus upon the overall performance of the company relative to managing contingent liability is often lost when no comparison or ranking of properties is performed. Only in this manner can effective decisions on capital expenditure, changes in management philosophy, etc. be made with the objective of minimizing long-term liability and increasing environmental management successes.

Although it is natural at an operating unit level to operate in a relatively short-sighted manner, that is, to minimize cost and maximize return, this approach is not necessarily compatible with long-term corporate goals. Changing mine management's philosophy at the operating level to the corporate objective, rather than the local objective, can be achieved in the application of the following management process.

ENVIRONMENTAL MANAGEMENT SYSTEM: STANDARDS AND PRACTICES DOCUMENT

The Environmental Management Systems (EMS): Standards and Practices Document is a key tool in developing management strategy. EMS provides a consistent approach to operating (and developing) properties and the ability to develop a relative comparison between properties.

The major aspects of the EMS are those dealing with the design and operation of mine waste project components which hold the highest contingent liability. These include:

- Tailings impoundments;
- Heap leach facilities;
- Water containment, treatment and discharge facilities; and
- Waste rock management facilities.

Specific performance criteria for the facilities should include:

- Performance objectives;
- Physical stability criteria;
- Geochemical stability criteria;
- Closure standards; and
- Reclamation objectives.

The ability, or appropriateness, of selecting performance criteria relative to local environmental regulations has significantly changed in the recent past. Introduction of environmental guidelines, such as those of the World Bank, the globalization of the mining industry and the growing environmental movement have imposed financial and political constraints on mining companies in this regard. The adoption of a consistent set of performance criteria to be applied on a worldwide basis is no longer philanthropic, it is essential in obtaining project financing and in developing company credibility.

PROJECT REVIEWS

The second step is to perform project reviews. Several mining companies have instituted a regular review of their operating properties by teams of managers from other properties with support from selected specialist consultants. From experience, the inclusion of personnel from other operations in the reviews has several benefits. First, this engenders a "group" philosophy and removes the perception of the review being by "outsiders".

The approach to the review is both to evaluate the current conditions and immediate history of the project and to evaluate the project relative to the EMS Standards and Practices document. To rank the properties in this regard, it is beneficial to establish a relative measure of performance rather than an absolute measure. That is, to normalize, for example, a new property against a long operating property's performance is of more benefit than simply establishing that one has a groundwater contamination problem where the other doesn't.

It is equally, if not more important, to institute a review of projects during the pre-feasibility and feasibility studies of project development. Frequently the studies are performed in discrete parts mine planning, process design, waste management, tailings disposal, etc. The objective of each component of the studies is not necessarily compatible with minimizing contin-

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gent liability. The paradigms set during feasibility can limit the ability to optimize the project relative to contingent liability.

The main areas considered in the reviews include:

- General Information;
- Management;
- Permits;
- Physical Stability;
- Water Management;
- Environmental Monitoring
- Mine Waste Characterization;
- Other Wastes and Potential Hazards;
- Other Environmental Concerns;
- Closure;
- Rights and Appropriations.

A key part of the review is the evaluation of the ability to close the mine both in its current status and at the end of the mine life. The evaluation and updating of the closure plan relative to any changed conditions and verification of modification of the closure cost estimate is necessary to define current liability.

Development of the FMEA and risk analysis can then proceed from the information gathered.

DEVELOPMENT OF FAILURE MODES EFFECTS ANALYSIS

The Failure Mode Effects Analysis (FMEA) is a systematic approach that identifies potential failure modes in a system, product, or operation caused by either design or process deficiencies. It also identifies critical design or process characteristics that require special controls to prevent or detect failure modes. A failure mode is not simply a break in a pipe or a dam failure. Rather, a failure mode is a condition or future condition that does, or will, not meet the performance criteria. With information developed in the site reviews, potential system failure modes, and consequences, can be identified.

There are various ways in which a system could fail. In addition to the type of "failure mode", the magnitude, location and timing of the failure mode may be equally important. For example, the magnitude, location and timing of a tailings impoundment failure may significantly affect the consequences (e.g., costs) of such an event. Similarly, the current lack of acid drainage from a waste rock management facility does not preclude its occurrence at some later date.

Following determination of the potential failure modes for a given mine system, specific consequences of that failure mode require identification. Such consequences may vary by failure mode and must be estimated based on available information, and where necessary, supplemented by scientific analyses. However, because available information is typically imperfect, there will be uncertainty in defining these consequences. In general failure mode consequences can be divided into the following categories:

Direct Failure Costs:

- Loss of operating revenue;
- Cleanup and facility repair;
- Property damage (including infrastructure);
- Legal (liability and fines).

Human Health and Safety:

- Public;
- Employees.

Environmental Damage Socioeconomic:

- Land use and property values;
- Aesthetics and quality of life.

Infrastructure Disruption:

- Access/Travel;
- Utilities.

Reputation and Confidence:

- Public;
- Regulators;
- Investors.

The likely consequences of each failure mode should be identified based on these categories. A narrative description of each failure mode and consequence should then be developed as well as the potential implications for the mining company.

RISK ANALYSIS

The various failure modes identified from the site inspection may not necessarily occur, and in many cases, are very unlikely to occur. To assume that they will occur would be excessively conservative. However, in some cases, the failure mode may occur more than once. The likelihood and uncertainly in the number of occurrences may vary among failure modes and must be addressed based on available information and supplemented by additional scientific analyses.

Although the primary emphasis of the FMEA is to evaluate contingent liability, the risk analysis process frequently has direct benefit to operations. The presence of a failure mode associated with a system for which there is no operational redundancy may have significant implications to operations with little to no environmental liability. For example, if a conveyer system to a crusher is subject to disruption due to a waste rock dump movement or an electrical switch station may be inundated by a pipeline break, simple mitigation measures may alleviate these effects.

With the general trend for operation of properties with shorter mine life, the importance of the performance criteria related to closure and reclamation increases. The significance of not achieving the closure performance criteria is also greater with a shorter mine life as the ability to correct or modify operations and facility management is less. That is, the occurrence of

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a failure mode in year three of a five-year project is more significant than its occurrence in year three of a twenty-year project.

Once the failure mode and consequences have been identified, the next step is to assess the likelihood of occurrence of each failure mode. While most of the occurrence assessments will be based on compliance of the particular system with the performance criteria established during the EMS Standards and Practices Document development, some degree of the assessments will be subjective and based on the professional judgement of the individual investigators.

RANKING SYSTEM

The next step is the ranking of each project component. Each component's "risk" level can be identified based on a combination of the consequences of each failure mode if it occurs and the probability of that failure mode occurring. In order to simplify the overall process, a risk-ranking matrix, similar to the one presented here (Figure 1), could be applied to each system failure mode and consequence analysis.

Increasing Impact ↑ / ← Increasing Probability	HP			LP
HI	16	15	13	10
	14	12	9	6
	11	8	5	3
LI	7	4	2	1

Figure 1. Ranking system.

The ranking of each system would be based on the professional assessment of the severity and significance of the failure mode impacts (i.e., HI = High Impact; LI = Low Impact), and the probability that the given failure mode would occur (i.e., HP = High Probability; LP = Low Probability). For example, a failure that is not likely to occur, yet carries moderately significant impacts may be ranked as a 6, while a failure that has slightly less impact significance, yet is considerably more likely to occur may be ranked as an 11.

In this way, it is possible to numerically rank individual mine systems at a given property. Based on the risk ranking of the individual systems, an overall site ranking can be assigned using a weighted-average approach.

Finally, to remove the process from being a relatively academic exercise it is necessary to complete a cost-benefit analysis. As mentioned above, some non-redundant systems maybe changed from an HI/HP status to LI/HP or HI/LP status with little to no cost. For example, relocating a pipeline to remove a hazard or accelerating reclamation of an inactive waste dump area may be readily achieved. Alternatively, replacing a tailings impoundment or relining a process solution pond may result in significant expense. Quantifying the cost-benefit of an activity provides a mechanism of prioritising expenditure at an individual property and between properties in a manner which may achieve environmental management and liability reduction objectives.

DESIGN FOR CLOSURE

Historically, mines were operated in the absence of a defined closure objective. Examples of the consequence of this are numerous and are in part the cause of today's negative public image of the mining industry. The cost of closure and site rehabilitation has resulted in some mining companies, if not legally, then technically becoming bankrupt.

Design for closure involves integrating the closure objective into mine development and operating plans. For each phase of a project and throughout the mine life, the ability to close the facilities must be evaluated in terms of the current and contingent liability this would involve.

On a day to day basis this approach is applied to operating decisions. For example: the evaluation of whether mining and leaching an ore zone is economic relative to the cost of environmental management and closure of the additional disturbance. Similarly the tendency of operations to try to extend the mine life can result in adverse conditions which compromise closure objectives. The decision of when to cease operations and close the facilities should be made based upon achieving closure objectives rather than sustaining cash flow.

CONSISTENT APPLICATION

For the most benefit, the above process should be performed on a regular basis over an extended period of time. Through consistent application of the above steps, a mining company can develop a ranking system that would provide the basis for cost-effective application of the finite resources available for managing environmental issues. The mining company can then evaluate how its environmental dollars are being spent relative to the most pressing environmental issues and liabilities that directly impact its operations.

Design for closure then becomes a consequence of the process. This is perhaps best illustrated by the case study of the Kennecott Ridgeway Mine.

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KENNECOTT RIDGEWAY MINE

The Kennecott Ridgeway Mine started operation in 1988. The project involved the mining of gold bearing ore from two open pits and the processing of the ore by cyanidation in a conventional CIL circuit. Mining and processing are scheduled to be complete in the last quarter of 1999. At the feasibility stage of mine development, a conceptual closure and reclamation plan was prepared. As mining advanced this plan was updated to account for the actual conditions encountered. In 1997, sufficient data were available to define a detailed closure and reclamation plan and commence its execution.

In order to develop a viable and cost effective closure and reclamation plan for the project, an integrated approach to all project components was warranted. From the pre-feasibility stage of the project, the adoption of a "design for closure" approach was made. Although this concept can, in some instances, result in an increase both in initial capital and operating costs, the ability to minimize long term liability and minimize closure and post closure costs can be realized.

Throughout the operating life of the mine periodic reviews have been performed. Progressively more detailed plans for closure were developed, costs estimated prepared and funds accrued for closure. One of the key closure objectives for the project was to achieve, as close to a walk-away status following closure as was possible.

The key components and influences upon the project's operational management and closure are:

- Acid Rock Drainage Management;
- Process Water Management;
- Pit Water Management;
- Tailings Impoundment Reclamation.

ARD MANAGEMENT

The mineralization at the mine involves the weathered profile of an epithermal deposit in which residual sulfide bearing materials increase generally with depth. In the upper zones, saprolite is barren of sulfides and contains little to no primary neutralizing capacity. In the less weathered or oxidized transition zone, the ore and waste rock contain sulfides, primarily as pyrite, and limited neutralizing capacity. At depth, the unoxidized zone existing within the host rock possesses significant neutralizing capacity.

Mining of the pits created both waste rock and exposed pit walls that are acid generating. Proactive identification of waste rock types allowed the segregation and management of the acid generating and potentially acid generating wastes. This involved both encapsulation and neutralization of the waste within the tailings embankment and in engineered waste rock disposal facilities. Temporary stockpiles of low-grade ore were also maintained with the collection and management of surface runoff from these areas.

As part of the ARD management, phasing of pit development was incorporated into the mine plan. In this manner acid generating waste rock from the North pit has been backfilled on the floor of the South pit and flooded.

The pit water and water contacting waste rock and the low-grade stockpiles has been used as process water make-up and, when necessary, has been treated and discharged under the projects NPDES permit. Following completion of mining in the South pit, surface water and pit water has been used for inundating the waste backfilled to the pit and flooding of the pit walls. A lime treatment system is used to buffer the water and maintain alkaline conditions.

Mapping of the pit walls has identified acid generating areas. Which are of limited extent above the ultimate pit lake level. Specific management of these areas includes their capping and stabilization.

PROCESS WATER MANAGEMENT

The project's process water circuit has been operated as a zero discharge facility. The consumption of water through tailings deposition results in an average deficit of water. As further described below, the process water at the end of the operations will be treated and consumed through the reclamation of the tailings impoundment surface. A simple hydrogen peroxide treatment circuit has been designed for process water treatment. Treated solution will be used to slurry the cover material for reclamation of the tailings impoundment. In this manner, the need to release treated process solution at closure is eliminated. Monitoring during operations has shown a rapid reduction in the process components in the tailings water. Both anaerobic and bacterial degradation of the cyanide complexes in the solution has resulted in nominal residual cyanide levels. The tailings also exist in a reduced condition at depth and have significantly decreased metal values due to reprecipitation as, and coprecipitation with, sulfides.

Monitoring of the groundwater draining from below the impoundment has shown no impact from the facility. Coupled with the physical containment of the impoundment, no long term impacts to surface or groundwater from process solutions can be identified.

PIT WATER MANAGEMENT

During mining, surface and groundwater were evacuated from the pits. Surface water was collected in a sump and recycled or discharged. Dewatering of the pit walls through a series of wells was also performed. Following significant storm events, the pits periodically stored excess water. This water would, over time, become acidic and its treatment with sodium hydroxide was performed prior to use or discharge.

With the backfilling of waste rock to the South pit, all surface water evacuated from the North pit and collected in the

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surface water management system is routed to the pit. At the end of mining this will continue with a projected flooding of the pit to near surface levels requiring an additional three to four years. Base amendments will be introduced to the influent water and/or by recycling the pit water through the base amendment circuit.

Zones of sulfides exist approximately 50 feet below the final pit water level. The subaqueous conditions produced following flooding will alleviate any potential degradation of water quality from these zones.

The water level in the South pit will be maintained approximately 10 feet below its natural outlet level for the period when the North pit is inundated. During the three to four years when the South pit reaches this level, the North pit will accumulate ground and surface water from direct precipitation. Partial backfilling of the North pit will be performed when mining ceases. This backfill will consist of temporary waste rock stockpiles, mine waste material from site regrading and from the removal of ramps and roads which were built with mine waste. The backfill will create a porous mass in the base of the North pit that will absorb water draining to the pit.

Once the South pit has been flooded, filling of the North pit will occur with the rerouting of surface and groundwater to the North pit from the South pit. An estimated ten years is required to flood the North pit. In a similar manner to the South pit, base amendments will be added to the influent water or recycled water to maintain an alkaline water chemistry.

The initial reclamation of the site following mining will include the development of a drainage system from the North pit to the South pit. During the period of pit flooding, this drainage system will develop into a natural wetland system. Once full, the North pit will drain to the South pit that will, with other surface water contributions, fill to its outflow level within approximately one year. Final release to the receiving drainage will then occur.

TAILINGS IMPOUNDMENT RECLAMATION

The tailings impoundment covers an area of approximately 300 acres and sits at the head of a small drainage basin. The embankment consists of a zoned fill made up of selectively placed waste rock from the pits and engineered encapsulation cells for acid generating materials. The embankment forms an approximately circular containment that rises approximately 200 feet above ground at its maximum height.

Tailings were initially discharged from a ring pipeline running around the embankment crest. This resulted in the formation of a concave impoundment surface and a central process water pool. Access to the pool and water return system involved the maintenance of a ramp constructed of waste rock.

The objective of the operation of the impoundment over the last two years of the mine life is to change the impoundment from a concave to a convex shape. The surface configuration will then drain to a spillway and, in post closure conditions, shed natural runoff from the facility.

To achieve this objective, the deposition system has been modified with the inclusion of a central discharge point. Through managed deposition, the pond is moved to the final spillway location. Once in its final location, deposition continues from the central discharge to achieve the final surface configuration.

At the end of ore processing, the mill circuit will be converted to process saprolite derived from the surface regrading at the site. Residual process solution will be removed from the impoundment to the process solution pond. This water will then be routed through the hydrogen peroxide treatment circuit and used to slurry the saprolite to the impoundment. No recycling of slurry water would occur until all process water in the circuit was treated, at which time slurry water and make-up water would be used to continue the saprolite placement.

In this manner, the slurry "cover" achieves two objectives. First, the residual process solution is consumed in the initial deposition of the saprolite and second, the system is maintained in a negative water balance throughout the regrading and capping of the tailings. This latter aspect alleviates the concern that accumulation of water on the facility could occur with the placement of a conventional haul and place cover. It also reduces the time for cover placement that would be required for stabilizing the impoundment surface and developing access for placement equipment.

Once the cover is in place, fast growing grass and growth promotion agents will be placed over the surface by aerial application. The grasses enhance stabilization of the cover and allow access to be developed for final surface treatment.

Over the subsequent one to two growing seasons, all runoff would be retained in the process solution pond and subject to final water quality, treated and released to the pits.

MODELS

To predict the behavior and evaluate the viability of the closure plan, a series of models were developed. These include: a project wide surface water mixing model; a consolidation, seepage and cover model for the tailings impoundment; and a project wide groundwater model.

Surface water mixing model

The objective of this model was to predict the water quantity and chemistry derived from various sources at the project and to predict water quality in the pits over time. The physical component of the model involved the development of flows and quantities for various nodes within the site. Each node was considered over the operating period, initial post reclamation period and for the final post reclamation period. Monitoring data for water chemistry for sources such as surface water, groundwater, interstitial tailings water, process solution water and pit

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water were input to the model. Data on the treated water chemistry were derived from laboratory and pilot scale testing. Initially, a mass balance model was performed with a conservative chemistry. For each of the pits, the predicted water chemistry was then evaluated for chemical equilibrium on an annual basis.

Through the modeling effort, the final water chemistry upon release to the natural stream system was predicted to achieve a quality equal to or better than national maximum contaminant levels (MCL's).

Limnological model

Part of the mixing model described above involved the assumption that the pits develop into a chemically and physically stable "lake". To verify this assumption, the potential stratification of the lake due to salinity gradients was modeled. In addition, a thermal gradient model was developed to evaluate whether sufficient thermal instability could occur for the lake to "turn-over".

The results of the model predict that the pits will develop into meromictic lakes exhibiting density stratification. No potential for turnover was shown.

Tailings water and cover model

Both a physical and chemical model of the tailings impoundment was developed to evaluate the probable quantity and quality of solution derived from the tailings mass and to evaluate the optimum cover configuration. Data from field investigations of the tailings were used to determine the probable consolidation of the tailings both under self-weight consolidation and under loading from the cover. These data include piezocone penetrometer testing and laboratory consolidation results. A series of finite difference consolidation models were performed.

To evaluate the effectiveness of the proposed cover, a combination model using the program SEEP/W and SOILCOVER developed by the University of Saskatchewan, was used. This allowed a prediction of the flux into and out of the reclaimed impoundment. Finally, the chemistry of the fluxes, based upon measured water chemistry was evaluated.

Based upon this model it is predicted that the impoundment will rapidly reach physical equilibrium relative to a final surface configuration and internal moisture regime. Release of solution containing process solution components is not predicted. In addition, no significant effect upon long term surface water quality is shown.

Groundwater model

To evaluate the potential effect of the pit flooding on groundwater flow and chemistry, a model of the project site was developed. This model incorporated site geology, climate, hydrogeology, the effects of the post closure mine facilities and the projected filling rates of the pits.

Throughout mining, the influence of the pit dewatering and of the removal of recharge from beneath the tailings area has been monitored by a network of wells. Once the initial model was calibrated to premining groundwater conditions, the model was then calibrated to the monitored drawdown over time. This resulted in a model that was then used to predict flux and groundwater flow over time with the flooding of the pits. In addition, a long-term predictive run was performed to establish the post reclamation equilibrium conditions.

The conclusions of the groundwater model suggest that a period of some twenty-five years is required for equilibrium to be reached. Based upon the predictive model, a solute transport analysis was performed using an assumption of conservative chemistry. From the mixing model predictions, the pit water chemistry was used and its travel time and dispersion and dilution over time were predicted.

The predicted impacts upon groundwater and upon surface water at points of groundwater discharge were then made. The results of the model predict negligible impacts to groundwater and surface water.

MONITORING

Monitoring of the South pit backfill and flooding has been performed since August 1997. The monitoring is focused upon water chemistry in the pit and upon detectable changes in the groundwater regime surrounding the pit.

To date, water chemistry has not exceeded the quality predicted and all constituent levels are below MCL's. Minor increases in groundwater level have currently occurred where groundwater flow is to the pit. Regrading of the tailings impoundment has reached an advanced stage with the pond successfully relocated to the ultimate spillway location. Continued monitoring suggests that the model predictions are currently reflecting actual conditions.

CONCLUSION

To effectively plan and perform the closure and reclamation at the Kennecott Ridgeway Mine, an approach was adopted in which all the project components influencing the closure were evaluated. Through adoption of a design for closure approach and through periodic review to identify and plan to minimize current and contingent liabilities, the mine has been operated to meet stringent environmental management criteria and to meet closure objectives. To facilitate the evaluation of the viability of the closure plan in terms of its meeting closure objectives, a series of models were developed. These models allowed the integrated closure and reclamation of the site in regards to surface water, groundwater and the physical stability of the post-reclaimed conditions. Monitoring of the reclamation is ongoing and will extend over a period of some 15 years until final formation of the pit lakes is completed.

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