DESIGN AND IMPLEMENTATION OF A STRATEGIC REVIEW OF ARD RISK IN RIO TINTO [1]

David G. Richards, Richard K. Borden, John W. Bennett, David W. Blowes, Mark J. Logsdon, Stuart D. Miller, Steve Slater, Leslie Smith, and G. Ward Wilson[2]

Abstract. Following an internal review of significant environmental risks in 2003, Rio Tinto developed, using a combination of in-house and external expertise, an ARD screening protocol to rank innate hazards at its mines and a second protocol to assess performance in key management areas during site-based risk reviews. Eight risk reviews were conducted in 2004 and another four in early 2005, at mines covering a wide range of commodities, operating methods and project stages. These reviews have proven successful in identifying and reducing ARD-related risks within Rio Tinto. Site-specific findings identified by these reviews are reported through corporate assurance processes with progress on agreed remedial actions being tracked semi-annually. Some common issues, covering aspects such as characterisation, groundwater monitoring and modelling, material segregation, cover design and flooding of workings, were identified at multiple sites. These have also been addressed by strengthening existing corporate environmental standards and guidance for ARD prediction and management. This paper summarizes the methodologies and the major findings of the first two years of the Rio Tinto program.

[1] Paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502

[2] David G. Richards is Principal Adviser, Environment, Rio Tinto plc, Bristol, U.K.. Richard K. Borden is Principal Consultant-Environment, Rio Tinto Technical Services, Bundoora, VIC, Australia. John W Bennett is a Senior Principal Research Scientist, ANSTO Minerals, Menai, NSW, Australia. David W. Blowes is Canadian Research Chair in Groundwater Remediation, University of Waterloo, Waterloo, ON, Canada. Mark J. Logsdon is Principal Geochemist, Geochimica, Inc., Aptos, CA 95003. Stuart D. Miller is Managing Director, Environmental Geochemistry International Pty. Ltd., Balmain, NSW, Australia. Steve Slater is Principal Consultant Manager, Rio Tinto Technical Services, Bundoora, VIC, Australia. Leslie Smith is Cominco Chair in Minerals and the Environment, University of British Columbia, Vancouver, BC, Canada. G. Ward Wilson is Chair in Mining and the Environment, University of British Columbia, Vancouver, BC, Canada.

7th International Conference on Acid Rock Drainage, 2006 pp 1657-1672
DOI: 10.21000/JASMR06021657

http://dx.doi.org/10.21000/JASMR06021657

Introduction

Rio Tinto is a large, diverse mining company listed on stock exchanges in London, Melbourne and New York. It manages over 60 mining operations, producing a wide range of commodities from Al to Zr, in over 20 countries. Its subsidiaries constitute six Product Groups – Aluminium, Iron Ore, Diamonds, Copper, Energy and Industrial Minerals – and activities such as exploration and technical support are organised on a Group-wide basis (Rio Tinto, 2005).

In 2003 Rio Tinto decided to carry out a review of the risks posed by the occurrence and management of acid rock drainage (ARD) across the Group. ARD is understood to cover a wide range of related phenomena including sulphide oxidation, metal leaching and the release of acid solutions or their derivatives, whether the net effluent is or is not acidic. This coverage corresponds with current trends in mine-waste geochemistry emphasizing geochemical reactivity and overall water quality outcomes and impacts, rather than focussing on low-pH conditions alone (e.g., Price, 2003.)

Drivers for the ARD risk review

The background to the decision to carry out the risk review lies in a series of actions taken by leading mining companies in the period 2000 – 2002. The Chairmen and CEOs of nine major mining companies formed the Global Mining Initiative (GMI) in 2000, with the objective of stimulating an independent analysis of mining's potential to contribute to the transition to sustainable development in society as a whole.

The GMI commissioned the Mining Minerals and Sustainable Development (MMSD) project that reported its findings in 2002 (MMSD, 2002). The MMSD report challenged the mining industry to improve its performance in a number of environmental and social areas, including the assessment of ARD.

The International Council on Mining and Metals (ICMM) was formed in 2002 to take forward the industry's response to these challenges. Rio Tinto was a founder member of the GMI and ICMM, and its chairman, Sir Robert Wilson, was the inaugural chairman of both organisations. This external engagement was mirrored by a shift inside Rio Tinto towards a more proactive approach to risks and opportunities facing the industry.

Specifically, the decision to carry out a strategic review of ARD risk arose from the process of reviewing and prioritising strategic risks that is carried out as part of the annual planning meeting of the corporate Health, Safety and Environment (HSE) department. The high priority attached to the issue in 2003 was prompted by several factors:

- There had been changes in corporate governance law in all the major jurisdictions in which Rio Tinto operates. These changes include the Higgs Combined Code for Corporate Governance and the Turnbull Report in the U.K., the Sarbanes-Oxley Act in the U.S.A. and the Guidelines of the Australian Stock Exchange. The common intent of these regulations is to ensure the identification, evaluation and management of all significant risks faced by the company as part of the company's fiduciary obligations to its investors.
- Rio Tinto's Environment Policy states that it will minimise harm to the environment (Rio Tinto, 2003), and the strategic HSE plan sets the approach as being proactive and risk-based. The lack of a specific assurance program covering ARD was seen as a significant gap in the management of risk in order to minimise environmental harm.

- History and experience within Rio Tinto and the global mining industry have shown that ARD can be a significant risk, leading to intensive technical management and costly remediation. In the late 1980s and 1990s, a variety of reports by governmental agencies and non-governmental organizations highlighted the magnitude and extent of ARD impacts (e.g., U.S. EPA, 1985; Kleinmann, 1989; Lyon et al, 1993; Harries, 1997). One example of the scale of risks within the Rio Tinto holdings is the Bingham Canyon Mine of Kennecott Utah Copper Corporation, where the management and mitigation of metal-rich and sulphate-rich groundwater plumes since 1990 has cost over US$300 million.
- The mining industry's past difficulty with predicting, preventing and managing ARD risk is an important factor in the lack of trust that still exists between the industry and several important stakeholder constituencies. Rio Tinto's reputation and future opportunities may be damaged by association in the absence of specific actions to address its own ARD risks.
- ARD risk findings have occurred regularly in other corporate environmental assurance reviews. These reviews are typically staffed by senior environmental professionals with general rather than ARD-specific expertise. It is possible that subject experts might recognise additional risks.
- Maintaining a Licence to Operate - both legal and social - and earning the trust necessary to be considered as a preferred development partner in countries and communities around the world both require Rio Tinto to demonstrate improved environmental performance, including reducing ARD risks and impacts.

Taken together, these factors led to the conclusion that a focussed risk review programme was needed. The model that had been used for the corporate review of other strategic technical risks was adapted to provide a program of site-based assessments of ARD risks and impacts, and of the measures in place to manage these. The programme needed to draw on specialist ARD expertise and to use rigorous and comprehensive protocols, addressing highest hazard sites first. The overall objective of the programme was to answer the question: *"Where do the majority of hazards posed by ARD reside within Rio Tinto and are these hazards being properly managed by the operations to minimize the environmental, financial and reputational risk?"*

Designing the ARD Risk Review Program

A review of extant tools and methodologies for the planned risk review programme was carried out by senior Rio Tinto staff, and this revealed that there were no suitable protocols available, either for the process of screening for innate ARD hazard across a diverse portfolio of mines or for the site risk assessment process. It was therefore decided to put together a team with the necessary expertise to develop these tools specifically to meet Rio Tinto's needs.

Experience gained in solving ARD problems in the Rio Tinto Group strongly suggested that the requisite expertise should cover a wide range of specific scientific, engineering and management disciplines. These include geochemistry, soil engineering, groundwater and solute transport modelling, gas transport and material management. A team of expert individuals with this range of skills and experience with a wide range of ore-deposit types and geographical factors, supplemented by ARD experts from within Rio Tinto, was invited to attend a workshop in Sydney, Australia in July 2003, following the 6th International Conference on Acid Rock Drainage (ICARD) in Cairns.

The objectives of the risk review programme were reviewed and refined at the workshop. Formal drafts for two protocols were developed, consisting of a hazard screening protocol for the group-wide operations, and a risk review protocol to be applied at individual operating units.

The primary objectives of the ARD risk review program, are:

1) to improve the understanding of ARD risks and their management across the group,
2) to reduce the risks posed by ARD at the operations,
3) to provide advice to businesses on international best practice in ARD issues and their management,
4) to build greater capacity within Rio Tinto to address ARD issues appropriately, and
5) to identify actions that need to be taken at the corporate level to ensure that ARD risks are adequately addressed in the future.

Hazard Screening Protocol

The hazard screening protocol was developed to identify where the majority of risks posed by ARD reside within Rio Tinto and to prioritize mines for visits by the ARD Risk Review program. The screening protocol was designed to assess all hazards posed by the release of sulphide oxidation productions including the formation of acidic and/or saline soils, the release of low pH contact waters, or the release of contact waters with circum-neutral pH but elevated salinity (i.e., total dissolved solids) or metals concentrations. The screening protocol ranks the potential ARD hazard posed by mining based upon the innate physical and chemical setting of each site. The hazard screening protocol was not intended as a commentary on how each operation is managing the hazards to reduce the overall risk; this is the function of the Risk Assessment Protocol described in the next section.

The screening protocol was designed so that data available as part of existing Rio Tinto documentation could be used to determine if there may be a significant ARD source at the site, as well as determining if there are dispersal pathways that could create environmental impacts at sensitive receiving environments. Data sources used in the ranking process included: geologic journals and texts, Rio Tinto annual internal reports, findings from previous general Rio Tinto health and environment reviews, maps, existing site summaries and climatological data. First-hand knowledge of conditions at some of the operating units was also available to the review team.

The broad issues that were examined as part of the assessment were assigned numerical values which were combined into the final hazard score As shown on Table 1, these are: geology (45%), incipient ARD risk (5%), scale of disturbance (25%), transport pathways (10%) and sensitivity of the receiving environment (15%). The identification and weighting of these factors was accomplished through an interactive, iterative process involving a group of ten technical experts. The emphasis in the screening protocol on geologic and hydrologic/hydrogeologic factors reflects insights developed from international applied research efforts detailed in such documents as Alpers and Blowes (1994), Blowes and Jambor (1994), Plumlee and Logsdon (1999), and Jambor, Blowes and Ritchie (2003), as well as the technical presentations and reports available through the first six ICARD meetings.

The weighting of the factors was refined until their influence on the ranking of a series of well known mines matched the professional judgement of the full team of technical experts involved. Details and examples are provided within the screening protocol for each ranking category within each factor so that scores can be assigned in a rational and repeatable manner.

Ore deposit type is the most heavily weighted factor in the screening tool, contributing a maximum of 30 points to the maximum combined score of 100 points. Many bedrock-hosted metalliferous ore bodies (such as porphyry Cu deposits) are formed by processes that are directly related to some type of sulfide mineralization. These deposits also typically contain abundant metals that may be mobilized if the ore body and surrounding country rock is exposed to accelerated surface weathering conditions by mining activities. Conversely, many near-surface, unconsolidated ore bodies (such as bauxite and evaporites) are formed by processes that would prohibit the formation of sulfide minerals and would oxidize or would destroy any sulfide minerals that were originally present in the parent material. Between these two extremes are ore bodies that exist under reducing conditions and so could contain sulfide minerals, but whose genesis is not directly related to sulfide mineralization (such as kimberlites and coal deposited under transitional fresh water to slightly brackish conditions). To designate a score for the ore deposit type, all deposits are assigned to one of five broad categories:

1) formation by active surficial processes in equilibrium with the atmosphere (0 pts),
2) formation by paleo-surficial processes or by active surficial processes that may be associated with sediments formed in anoxic environments (7 pts),
3) formation is not directly associated with sulfide mineralization but where sulfide mineralization is possible (14 pts),
4) formation is directly associated with low-grade (< roughly 10% total sulfur) acid generating sulfide mineralization (23 pts), and
5) formation is directly related to high-grade (> roughly 10% total sulfur) or very reactive, acid-generating sulfide mineralization with low potential for acid neutralization (30 pts, or maximum).

Incipient ARD risk is highest for young operations and operations that have recently undergone a major change (such as a shift from oxide to primary ore) because they are most likely to be within the geochemical and hydrologic lag period between the time when sulphide-bearing materials are exposed and the time that ARD becomes apparent. The score for water availability is based on annual local precipitation divided by the annual local evaporation, which provides an indication of potential water flux through the system, which in turn is one indicator of the possible magnitude of solute loadings from the mineral waste to the receiving environment.

The screening procedure assumes that impacts to water resources are likely to be greater when there is high flow transporting ARD reaction products than when there is little flow. Because the screening procedure was applied before any site-specific reviews or detailed reviews of extant hydrologic reports, the level of detail needed for a thorough hydrogeologic flow-and-transport analysis could not be undertaken at this stage. Instead, water-availability was used as an index of magnitude of issues associated with the pathways analysis that would be evaluated in detail later in the process. As shown in Table 1, the hazard-screening was weighted very heavily toward source characterization, considering that the pathways and receiving environment aspects would be addressed through the full risk assessment process, where mitigation and management can be analysed in detail.

These weighted factors can produce a maximum score of 100 points. The specific scores within each factor were developed for specific sites by technical consensus among the ten senior professionals on the ranking team. The development of consensus among diverse, senior professionals is not necessarily a simple or short matter, but its contribution to the reliability of the protocol is considered extremely valuable.

Table 1. Factors used in the hazard screening protocol.

Broad Issue	Factor	Weight
Geology	Ore Deposit Type	30%
	Host and Country Rock Neutralization Potential	10%
	Known ARD Issues on Site	5%
Incipient ARD Risk	Time Since Last Major Operational Change	5%
Scale of Disturbance	Total Waste Stored on Site	15%
	Footprint of Disturbed Area	10%
Transport Pathways	Water Availability	7%
	Metal Released to the Environment*	3%
Receiving Environment	Proximity of Surface Water Bodies	5%
	Alkalinity of Water Body or Groundwater	5%
	Proximity of Protected or Inhabited Areas	5%

Note: * Refers to the dissolved flux of metals that are discharged to the environment through approved permitted discharge points and approved operating practices.

During the screening process, approximately 70 projects, operating mines or closed sites managed or partially owned by Rio Tinto were assessed. Managed operations scored from as low as 17 points to as high as 78 points. The composite scores were used to group the operations into four broad ARD hazard classes: low, moderate, high and very high. Five managed sites received a very high ARD hazard rating. All these sites were very large tonnage, sulfide-bearing, primary gold or porphyry copper deposits with known ARD issues. The six mines or developments that received a high ARD hazard rating were more diverse and include coal, diamond, uranium, copper, zinc/silver and nickel deposits. Conversely, almost all of the low hazard sites are associated with the production of minerals such as salt, bauxite, borate, talc and channel iron ore. The twelve ARD risk reviews conducted to date have confirmed that the screening protocol successfully ranked the very high, high and upper moderate sites.

<u>Risk Review Protocol</u>

The risk review protocol focuses on how each operation is managing the innate ARD hazards posed by the ore body and on setting to reduce the overall financial, environmental, health and reputational risks. The risk review protocol was designed to assess all hazards posed by the release of sulphide oxidation products including the formation of acidic and/or saline soils, the release of low pH contact waters, or the release of contact waters with circum-neutral pH but elevated salinity or metals concentrations. The protocol is also intended to be applicable to a wide range of commodities and operations including exploration and development projects, active mines and closed sites. In order to minimize the development of future liabilities, it is intended to identify latent as well as current issues with particular attention to the long-term implications of current management strategies and practices.

The review protocols are divided into eleven key performance areas that cover all aspects of successful ARD management (Table 2). Individual elements that contribute to each key performance area are also listed. As with the screening procedures, the individual elements represent a holistic approach to the characterization and management of ARD, consistent with the "toolkit" approach proposed by Plumlee and Logsdon (1999) and reflecting recent progress in the science and engineering of mine-waste management, such as advances in characterisation techniques (Miller, Robertson and Donahue, 1997), and understanding of water and gas transport in tailing and waste-rock (Robertson, 1994; Jambor, Blowes and Ritchie, 2003).

Within the protocol, a series of performance indicators are provided for each element. These performance indicators are grouped into two or three levels. Level 1 indicators are good practices that generally represent the minimum level of knowledge or management that all sites should attain in order to address ARD issues. Level 2 indicators represent best practice, and level 3 indicators would only be implemented as part of more advanced, site-specific studies and/or management programs. Higher levels of performance may or may not be required at all sites. However, in general, sites with greater ARD hazards will need to implement higher levels of performance to characterize and mitigate the risks posed by ARD. Common shortcomings and problems associated with each element are also listed. These describe some common mistakes or misconceptions that have been observed at other mines around the world and that reviewers may expect to encounter in the future. For example, under the heading "Physical Characteristics of Waste", a common problem can occur when a small sample set has been used to characterize a large mass of waste material. Under "Materials Management", it may be the case that ARD data and knowledge resides in the Environment Department and is not integrated in the mine planning process.

The risk review protocols are not intended to be used as a checklist. They are intended for use as a memory aid for review teams, to list common issues, to prompt appropriate lines of inquiry and to promote consistency between reviews at different operations. Individual performance indicators may or may not be applicable based on site-specific conditions and histories, data requirements and management strategies. At mines where ARD is not anticipated, such as fully oxidized ore bodies, it may be sufficient if elements in the "Site Baseline Characterization" and "Waste Material and Wallrock Characterization" key performance areas have been addressed (Table 2). If these initial assessments indicate that all of the materials exposed or disturbed by mining will be geochemically benign, then the remaining key performance areas are largely redundant. It is worth emphasizing that the assessments need to be applied to all sites and site materials, including overburden, mineral processing wastes and even some construction materials.

Table 2. Key performance areas and elements used in the ARD risk review protocol.

Key Performance Area	Element
Site Baseline Characterization	Characterization of Existing Mine Wastes
	Climate
	Hydrology and Hydrogeology
	Surface and Groundwater Chemistry
	Ecosystem Characterization
Waste Material and Wall Rock Characterization	Geologic Setting
	Geochemical Characterization of Rock Masses and Process Wastes
	ARD Geochemistry of Pit Walls and Workings
	Physical Characteristics of Wastes
Materials Management	Integration of ARD Characteristics into Mine Planning
	Design of Waste Disposal Facilities
	Waste Material Management
ARD Generation Processes	Sulfide Oxidation
	Oxygen Transport
	Oxidation Products and in situ Chemical Reactions
	Infiltration and Internal Water Movement
ARD Migration Pathways and Fluxes	Surface Water Discharge and Contaminant Loading
	Groundwater Flow and Contaminant Flux
Potential Receiving Environments	Assimilative Capacity of the Receiving Environment
	Ecological Sensitivity of the Receiving Environment
Integrated Conceptual Understanding	Conceptual Models
	Numerical Models
	Development of Performance and Closure Criteria
ARD Mitigation Program	Mitigation Strategy
	Implementation of the Mitigation Strategy
Monitoring and On-Going Assessment	Monitoring Strategy
	Data Management and Assessment
	Feedback Mechanisms
Management Skills and Resources	Clear Accountabilities and Roles
	Institutionalized Procedures and Information Management
	Adequate Resources
Stakeholder Relationships	Stakeholder Relationships

Implementing the Risk Review Program

The review process at each site is initiated by a high level contact between the Rio Tinto Corporate Health Safety and Environment project manager and the Operation's Managing Director. After the timing and scope of the review have been agreed upon, a Terms of Reference describing the ARD Risk Review process is issued to the operation. The review teams are generally comprised of one to three external experts and one to two Rio Tinto personnel, all of whom have not been previously engaged at the mine. The size and expertise of each review team is selected to best address the scale and likely issues at the mine. Reviews typically involve some initial offsite document and data review followed by four to five days on site. Large sites with complex operations and/or ARD history, which are challenging to complete in a five-day site review, involve larger review teams.

During the review information is gathered via field inspections, interviews with key technical and management personnel and detailed review of key documents and data sets. The style of the reviews is collaborative not confrontational. They are designed to identify risks and practical solutions by maximizing the informal discussions between site personnel and the review team. The findings of each review, in which risks are identified, described and classified, may arise if deficiencies are noted in any of the key performance areas or elements detailed in the ARD Risk Review Protocol. As with the screening evaluation, the findings of the site review are consensus positions developed by the entire review team. The site review concludes with a debriefing for the senior managers, including the MD, which addresses the major findings of the review team.

At the close-out meeting, the main point of discussion between the review team and senior management is frequently the classification of particular findings, as each category has a different corporate requirement for follow-on activities. There is commonly less debate about the content of the findings.

A draft report is provided to the site for comment within one week of the site visit. Risks associated with ARD issues at the mine are captured in a series of findings which describe the current situation, highlight the potential risks and suggest a general plan of action to reduce the risks to acceptable levels. Each finding is assigned a ranking of critical, high, moderate or low. The rankings are based on a set of financial, environmental, health and community criteria that are listed in the ARD Risk Review Protocol. The protocol includes specific examples related to ARD for each level of risk ranking.

Significant emphasis is placed on ensuring consistency in the rankings assigned to findings during different reviews. Elements of technical, financial and reputational risk generally contribute to each finding, and the last two of these may be more variable in different cultural, legal and regulatory settings than the first. The main objective is to ensure that the technical basis for risk assessment and characterisation is consistent wherever Rio Tinto operates.

The report undergoes reviews by the operation, Rio Tinto Technical Services and Rio Tinto Health Safety and Environment before being issued as final. The reviews are intended to ensure that the reports are:

1) factually accurate and fair,
2) consistent with reviews at other sites, and
3) supported by all Rio Tinto stakeholders.

The final report is formally issued to the appropriate Product Group Chief Executive, the Head of Rio Tinto Health, Safety and Environment and to the operation.

Outcomes of the 2004/2005 Program

ARD risk reviews were conducted at twelve mines in 2004 and the first half of 2005. These mines were identified by the hazard screening protocol as having a higher potential ARD risk, given their geology, scale and setting, relative to other Rio Tinto operations. The reviews were conducted at a diverse range of Rio Tinto managed operations including development projects and open pit, open cast and underground mines producing Cu, Au, Zn/Ag, diamonds, Ni, U and coal. Mines were visited in North America, South America, Australia, Africa and Asia. The review program has assessed operations across the full spectrum of mine life, from projects in pre-feasibility evaluation to active mines and mine sites engaged in closure.

All of the visited operations were found to be in compliance with pertinent government regulations and with permit conditions related to ARD. However, compliance does not necessarily guarantee that ARD is being managed in the most practical, robust and cost-effective manner. Permits held by operating mines often give permission to manage ARD issues in a particular manner, but if the system does not behave as expected at the time permits were developed, it is the responsibility of the operation to remediate those impacts, whatever the resources and cost required. Nor does regulatory compliance alone guarantee that the operation is positioning itself for successful closure. The full difficulties and costs associated with ARD management are often hidden during the period of active operations because of long geochemical or hydrologic lag times and because water and solutes can be stored in the process water circuit or co-disposed with tailings. However, at closure these relatively low-cost management options no longer exist.

There were several classes of issues that were noted as high or moderate findings at a number of the operations that were visited. These types of issues may be expected to pose risks and require additional management attention, not only for Rio Tinto mines, but throughout the mining industry.

Geochemical Characterization of Materials

Inadequate characterization of materials was a common issue. If the long-term geochemical behaviour of all materials that would be disturbed or exposed over the full mine life is not defined, it is difficult to select appropriate management techniques during operation and closure. Rio Tinto mines that have obvious ARD issues have generally performed basic characterization work on a broad suite of materials. At these mines the findings generally reflect the need for more specialized testing to refine materials management programs or closure designs. For waste materials that have long lag times before the onset of ARD or for materials that may generate neutral drainage with elevated metals or salinity, the basic characterization work has sometimes been inadequate. In particular, potential environmental problems that may be caused by neutral drainage with elevated magnesium sulfate concentrations, a special case of elevated salinity, are commonly underestimated. At some operations there is also a general perception that rock with total sulfur values of less than 0.3 percent does not pose a water quality risk. However, at several Rio Tinto mines, acidification risks have been noted, and special handling has been implemented, for materials with total sulfur values as low as 0.05 percent, especially where there are special conditions in receiving environments. Typically, a few very simple tests would be sufficient to allow materials to be classified into those that are inert, those that provide neutralizing capacity, and those that may require special handling because of salinity, acid generation or metals leaching issues. A clear lesson from the reviews was that as a minimum, total S and neutralisation potential data should be available for a representative suite of samples from all rock types and process materials, and that this suite of samples must be expanded as additional rock types are encountered during mining.

Monitoring of Potential Groundwater Impacts

Insufficient monitoring of groundwater quality and groundwater flow paths near potential contaminant sources contributed to high or moderate findings at a number of the operations visited. In general, groundwater impacts are not as intensively monitored and managed as surface-water discharges. Insufficient monitoring may allow large liabilities to accumulate in the subsurface before they are eventually detected. In some cases groundwater monitoring wells had not been installed down gradient from all mineral waste storage facilities with the potential to degrade contact water quality. In other cases, monitoring was occurring too far down gradient or at too great a depth to provide early warning of groundwater impacts.

Management of Groundwater Impacts

Insufficient understanding of subsurface migration processes or a lack of clear requirements and goals inhibited the effective management of groundwater impacts at a number of the operations visited. Many of the mines visited do not have formal groundwater permit limits or designated groundwater compliance points. In many jurisdictions, the ambiguous wording of laws, regulations and permits relating to groundwater quality protection make it difficult to determine what an acceptable level of groundwater impact due to ARD may be. Similarly, if the behaviour of the groundwater system is not well understood, it is difficult to predict how solutes will migrate and to predict future contaminant concentrations at key locations such as aquifer boundaries, extraction wells or seeps and springs. Without a clear set of groundwater quality criteria, it is difficult to optimize waste management, cover design and water management programs. A finding of the review programme is that, where such clarity is not available from external requirements, it is the responsibility of the project or operation to define performance criteria, subject to appropriate corporate guidance.

Waste Rock Segregation

Lack of a waste-rock segregation program or the need to refine an existing segregation program contributed to high or moderate findings at a number of the sites visited. For mining operations that produce waste rock or spoils with different geochemical characteristics, segregation may be an important management tool to minimize ARD liabilities. Mines that produce a small volume of geochemically adverse material may be able to selectively place the material to minimize its potential impacts. This could include strategies such as minimizing the reactive waste footprint, encapsulation, placement below the ground water table and mixing with net-neutralizing material. Conversely, if only a small amount of geochemically benign material is available, it may be used to best advantage as a growth media, a capping material or as construction material. As described previously, several operations do not have an adequate understanding of the geochemical behaviour of their minerals wastes to determine if segregation is a viable risk minimization strategy. Furthermore, very few sites employ modelling tools that enable the effectiveness of different selective placement strategies to be quantified. Even at mines that have adequate waste characterization programs, there may be some reluctance to implement or expand segregation programs because they can increase the complexity of waste rock disposal and usually increase the short-term costs of mining. These increased costs are readily apparent and are incurred immediately, whereas the benefits, even if strongly net positive, may not be realised until the intermediate or long term.

Cover Design

At several mines inadequate consideration has been given to the need to minimize water infiltration or oxygen ingress. At others the proposed cover designs were inadequate to meet their required performance criteria. Although most mines in arid and semi-arid climates were aware of the potential benefits of store-and-release covers to minimize infiltration, the dominant controls on cover performance were not always well understood. Conversely, at some mines there was a danger that expectations of cover performance were too high with respect to reductions in water infiltration, oxygen ingress and contaminant loads. Limitations on long-term cover performance were not adequately acknowledged. Insufficient effort was made at several sites to quantify infiltration rates through waste materials with and without covers, and few sites had measured O_2 transport into and through the wastes. Without this information it is difficult, if not impossible, to estimate potential contaminant loading to receiving waters. It is also not possible to weigh the benefits of different cover designs versus their cost. The lack of integration between infiltration-limiting cover designs and revegetation programs was noted at most of the operations that had active cover-design programs. The personnel responsible for the revegetation program at a given mine are often not in the same group which is managing the ARD program. Lack of communication between these two groups can result in two different and sometimes incompatible visions of what the final landform needs to look like. For example the use of compacted layers for infiltration or oxygen control may not be compatible with the deep-rooted climax vegetation required by the revegetation program.

Flooding of Workings

The chemistry and hydrogeology of water bodies that will form in flooded workings after closure required additional study at most of the mines visited. For many open pits, closure details are poorly defined because the final geometry of the ultimate pit surface is not known and there is a lack of geochemical data for the rock that will be exposed on the ultimate pit walls. In many jurisdictions, the guidance on acceptable water quality within pit lakes is minimal and it is not entirely clear what the water quality goals should be. For example, in some cases, any pit-lake water quality may be acceptable as long as the lake is terminal (does not allow any outward surface or groundwater flow), in others it may be required that the water quality does not pose an exposure risk to water fowl and livestock, and in others the pit lake may be required to meet water quality standards based upon chronic aquatic exposure limits. Block cave mining is being conducted or planned at several of the operations visited. The increased porosity and permeability of the caved rock mass ensures that the flux of oxygen and water into the materials is greatly increased and creates a complex hydrogeologic and geochemical system that is significantly different from a traditional open pit. However, it is not clear that the mining industry as a whole has a good understanding of the potential long-term impacts of block cave mining on groundwater and pit lake water quality.

Response to the Program

Operational Level

Several of the mines that were visited by the ARD risk review program have requested follow-up technical support from Rio Tinto Technical Services. Others are responding to the findings using in-house expertise or external consultants. Based upon the most recent six monthly reporting results (mid 2005), approximately 20% of the high and critical findings identified by the reviews have been fully addressed. Work is ongoing or detailed action plans have been developed on another 45% of the significant findings and work remains to be initiated on 35% of the findings. Given the strategic nature of many of the findings, and the long lead times required to design and implement some of the studies and corrective actions, it is anticipated that reporting on many of the findings will continue for several years. As a result of the reviews, major geochemical characterization programs have been initiated at several mines and new waste rock segregation policies have already been implemented at two mines.

Improvements in water management, cover design programs, groundwater monitoring and groundwater management have also been initiated at several operations.

Corporate Level

The findings identified by the risk review process are reported to the appropriate Rio Tinto Product Group Chief Executive, so that he/she is alerted to the risks posed by ARD at the mines within his/her product group. Progress made towards addressing high and critical findings must also be reported on a six-monthly basis through Rio Tinto corporate assurance procedures to ensure that the risks identified by the reviews are being reduced in a timely manner.

The definition and classification of these issues and incidents are set out in detailed guidance to ensure consistency of approach. The 6-monthly report information, including the significant findings of the ARD risk reviews, is compiled and checked by the corporate HSE department, prior to review by the CEOs of each of the six product groups.

Progress in addressing moderate findings from the ARD Reviews is assessed as part of the on-going, general corporate health and environment review assurance process, for which site reviews occur at least once every four years. If the operation has made insufficient progress in addressing a moderate finding from the ARD Risk Review, it may be elevated to a high status by a subsequent health and environment review.

The development of the risk assessment protocol has also improved the identification and evaluation of ARD risks in investment decisions. The protocol has been incorporated into acquisitions due-diligence procedures. Two of the review visits have been to advanced projects that have reached the pre-feasibility study stage. The role of the risk review in such cases is to contribute to the early identification of potential ARD issues and to provide input to project design options to reduce ARD risks. These actions are intended to remove or reduce the risk that ARD will be a significant issue in future Rio Tinto operations and businesses.

Rio Tinto has a set of environmental standards that set out the requirements of each subsidiary business, each supported by detailed guidance. The results of the ARD risk review program have been used to strengthen the standard and guidance for ARD prediction and control. Corporate audits of compliance with this and all other environmental standards will give additional information on the status of ARD risk management in Rio Tinto. The integrated audit allows for the identification and assessment of areas where risk management between standards should be linked, such as water and ARD, Environmental Management System and ARD, land stewardship and ARD. The ARD risk review program has also provided a major input to the Rio Tinto closure standard and the audits of compliance with this.

In addition to the ARD risk review program, Rio Tinto has been developing an ARD strategy since 2004. The ARD strategy will provide the policy and strategic planning framework so that ARD risks and their management can be integrated into all Rio Tinto's procedures and decisions. The results of the ARD risk reviews have been instrumental in focussing the ARD strategy working group on areas for improvement.

Future Actions

The ARD risk review program has moved on from the 8 sites visited in 2004 to review a further 7 sites in 2005, representing the next grouping of operations in the hazard ranking list. Significant issues have been found at all sites, though the number and severity of findings has decreased as the process moves from Very High to High- to Moderate-Level sites on the initial hazard ranking list. The full risk assessment methodology represents an appreciable cost, and at some point these costs will outweigh the benefits in terms of risk reduction.

In recognition of this, a diagnostic tool will be developed in 2005 and 2006 to enable sites to carry out a facilitated self-assessment of ARD risk. This tool is based on the Rio Tinto environmental standard for ARD prediction and control and the ARD risk assessment protocol. Its implementation by operations will include an element of external expertise to ensure that the rigour and consistency of the ARD reviews are not lost. Use of the tool will be suitable for low-moderate hazard operations and for repeat assessments of operations already visited, and it is expected that its use and application would be reviewed by the general, periodic HSE reviews and routine reporting by operations to corporate HSE.

In addition, the corporate Health and Environment Review programme, which reviews strategic issues and risks at all operations on a 4-year cycle, will use the ARD hazard screening protocol to determine which of the forthcoming planned reviews should include a team member with specific ARD expertise.

There has also been a change in emphasis from assessing ARD risks and ensuring that they are reduced at existing operations to providing the risk assessment as an input to design of advanced projects. In this way the combined good practice advice of the external experts and the experience gathered from the parts of Rio Tinto where ARD is a risk can be contributed to ensure that the next generation of mines have the best possible chance of preventing or at least effectively controlling ARD.

Conclusions

Rio Tinto believes that the ARD risk review program has been a success. Key areas of high value include the following.

- Technical – both ARD ranking and risk protocols have stood the test of implementation at sites across a wide range of ore deposits and climates.
- Operational – reviews have generally been well received by the operations, who feel that they are useful. They have resulted in real improvements in ARD management at operating sites.
- Corporate – identification of ARD risk present at operations and assurance of significant ARD risk reduction and mitigation prior to closure.
- Institutional – capacity for ARD issue management in Rio Tinto improved, at both operating mines and in planning future generations of mines
- Professional – high level of collaborative interaction between site staff and experts.
- Financial – although the costs of establishing and implementing the program have been significant, actions on findings are likely to result in substantial reductions in the financial and environmental liabilities.

Taken together, the benefits listed above are of great value to Rio Tinto. The authors believe that the approach taken throughout the risk review program – that of development of rigorous diagnostic tools in collaboration with external experts and the use of these tools in a consistent process interactively with site staff – constitutes good practice in ARD risk management in the mining industry.

Whether the list of value and benefits should include higher reputational standing with different stakeholder constituencies is undetermined. Reputation is earned and granted by each constituency based upon what it can see and verify about a company's performance. It will take time for the verifiable consequences of the actions described in this paper to be delivered. Continuing to carry out technically sound reviews of risk using consistent, proven processes will be necessary for as long as mining projects are conceived, designed, built, operated and closed. The authors believe that the approach described in this paper is a major step towards institutionalising the capacity in Rio Tinto to do this as a normal part of its business.

Literature Cited

Alpers, C.N. and D.W. Blowes (Editors), 1994. Environmental Geochemistry of Sulfide Oxidation. American Chemical Society Symposium Series 550,Washington DC, USA, 681 p.

Blowes, D.W. and J.L. Jambor (Editors), 1994. The Environmental Geochemistry of Sulfide Mine-Wastes. Mineralogical Association of Canada Short Course Series Vol 22. 438 p.

Harries, J.R., 1997. Acid Mine Drainage in Australia: Its Extent and Future Liability. Supervising Scientist Report 125, Supervising Scientist, Canberra. 104pp.

Jambor, J.L., D.W. Blowes, and A.I.M. Ritchie (Editors), 2003. Environmental Aspects of Mine Wastes. Mineralogical Association of Canada Short Course Series Volume 31. 430pp.

Kleinmann, , R.L.P., 1989. Acid mine drainage in the United States – Controling the impact on streams and rivers. *In:* 4th World Congress on the Conservation of Built and Natural Environments: University of Toronto, p. 1-10.

Lyon, J.S, T.J. Hilliard, and T.N. Bethell, 1993. Burden of Guild: Mineral Policy Center, Washington, D.C., USA, 68 p.

Miller, S., A. Robertson, and T. Donohue, 1997. Advances in Acid Rock Drainage Prediction Using the Net Acid Generation (NAG) Test. *In:* Proceedings of the 4th International Conference on Acid Rock Drainage, Vancouver. Volume II, p. 535-549.

MMSD, 2002. Breaking New Ground – Mining, Minerals and Sustainable Development. Earthscan Publications Ltd., London, U.K. and Sterling, VA. 441 p.

Plumlee, G.S. and M.J. Logsdon (Editors), 1999. The Environmental Geochemistry of Mineral Deposits, Part A: Processes, Techniques, and Health Issues. Society of Economic Geologists, Reviews in Economic Geology, Vol. 6A. 371 p.

Price, W.A., 2003. Challenges Posed by Metal Leaching and Acid Rock Drainage, and Approaches Used to Address Them, *In:* J.L. Jambor, D.W. Blowes and A.I.M. Ritchie (eds.), Environmental Aspects of Mine Wastes. Mineralogical Association of Canada, Short Course Serries vol. 31, p. 1-10

Rio Tinto, 2003. The way we work- our statement of business practice. p. 8-9. Rio Tinto plc, London, U.K. and Rio Tinto Limited, Melbourne, Australia. 13 p.

Rio Tinto, 2005. 2004 Annual review – Meeting global needs for minerals and metals. Rio Tinto plc, London, U.K. and Rio Tinto Limited, Melbourne, Australia. 56 p.

Robertson, W.D., 1994. The Physical Hydrology of Mill-Tailings Impoundments. *In:* Blowes, D.W. and J.L. Jambor (Editors), 1994. The Environmental Geochemistry of Sulfide Mine-Wastes. Mineralogical Association of Canada Short Course Series Vol 22. p. 1-18.