PASSIVE TREATMENT OF EUROPEAN MINE WATERS: THE EUROPEAN COMMISSION'S 'PIRAMID' PROJECT

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ABSTRACT

Passive treatment of mine waters was introduced to the UK in the mid-1990s and is now spreading to mainland European countries. To facilitate the wider uptake of the technology, the European Commission has funded a major R&D initiative entitled 'PIRAMID' (Passive In-situ Remediation of Acidic Mine/Industrial Drainage). This research project will run for the three years ending 28th February 2003, and has a budget of €1.5M. PIRAMID is concerned with both hydrogeological and engineering aspects of passive treatment, which research teams in 6 European countries are addressing collaboratively. Key elements of PIRAMID research include the following:

- hydrogeological and institutional obstacles to the wider use of passive treatment in areas with particular constraints, namely:
  - eastern Europe (under-developed economies)
  - southern Europe (semi-arid climates)
  - northern Europe (cold climates).

- Further development of existing methods, and evolution of new techniques, to facilitate passive treatment of the full range of European minewater types (including arsenic-rich waters, cyanide-rich gold processing effluents and uranium mine drainage).

- Development of engineering guidelines to foster uptake of "state-of-the-art" passive treatment technologies (for both polluted groundwaters and surface minewater discharges).

Dissemination of PIRAMID outcomes will be primarily via the project web-site at http://www.piramid.org

Key words: Europe, passive treatment, wetlands, reactive barriers

INTRODUCTION

Europe has one of the longest histories of mining in the world with extensive complexes of room-and-pillar workings dating to the Neolithic (Holgate, 1991), and widespread remains of industrial-scale mining undertaken by the Phoenicians and the Romans (Shepherd, 1993). Needless to say, this long history of mining has not been without its environmental consequences, some of which have persisted for thousands of years. In view of the potentially long time-scales over which water pollution from abandoned mines may persist (e.g. Younger, 1997a; Wood *et al.*, 1999), there has been increasing interest within and beyond Europe in the development of methods for mine water treatment / pollution prevention which can operate over decades or even centuries with little maintenance. The greatest stimulus to the search for such methods in Europe was provided by the widespread closures of coal mines and some metal mines in the UK during the early 1990s, which led to extensive surface water pollution (Younger, 1993, 1998a; National Rivers Authority, 1994). Public outcry prompted the first steps towards a national strategy for dealing with the legacy of water pollution from recently- and long-abandoned mines. As regulators came to appreciate how long polluted discharges from mines can persist after abandonment (Younger, 1997a; Wood *et al.*, 1999), interest quickly grew in alternatives to conventional treatment technologies, favouring in particular solutions which operated with minimal maintenance (Younger, 1997b). Fortunately, such solutions had already been the subject of considerable research and engineering experience in the United States. The timely publication of the U.S. Bureau of Mines' (USBM) recommendations on the passive treatment of coal mine drainage (Hedin *et al.*, 1994) proved serendipitous for the UK mining and water industries, and the USBM design guidelines enjoyed rapid and enthusiastic uptake (Younger, 1995; Younger and Harbourne, 1995; Younger, 1997b). By the end of the year 2000, 25 full-scale passive mine water treatment systems (and a further 6 pilot systems) were in operation in the UK (Table 1), all but two of which were treating discharges from abandoned mines rather than active mines (Younger, 2000).

Table 1 - Summary of known passive mine water treatment systems in Europe, December 2000

Country	Aerobic Wetlands	Anaerobic wetlands	RAPS[a]	Reactive barriers	Other[b]	TOTAL
England	10	2	1	1	3[c]	17
France	1	-	-	-	2[d]	3
Germany	-	1	-	-	-	1
Norway	-	1	-	-	-	1
Sweden	1	1	-	1	-	3
Scotland	5	-	2	-	-	7
Slovenia	1	-	-	-	-	1
Spain	1	2	1	1	-	5
Wales	2	1	2	-	-	5
TOTALS:	21	7	6	2	5	41

Notes: [a] Reducing and alkalinity producing systems (= SAPS of Kepler and McCleary, 1994). [b] Types specified in footnotes. [c] Comprising two closed system limestone beds for Zn removal (see Nuttall and Younger, 2000) and one SCOOFI filter (see Younger, 2000, for further details). [d] Oxidation ponds for arsenic removal at Carnoulès; limestone drain for gold mine effluent at Loperec.

Transfer of technology from the USA was also responsible for the initial uptake of passive mine water treatment in Spain, though by the late 1990s, collaboration with UK researchers and engineers was also fostering the more widespread introduction of the technology in that country (e.g. Laine, 1998; Ordoñez *et al.*, 1998, 2000; Younger, 1999). At present there are five systems operative in Spain, of which three are pilot-scale (Table 1). To judge from the author's own experiences in Spain, the lack of full-scale systems in that country to date reflects two fundamental concern over the viability of open-air wetland treatment systems in semi-arid and arid regions:

(i) In hot, dry climates, evaporative concentration of contaminants in open-air wetlands may serve to counteract the beneficial geochemical processes which generally remove problematic metals from solution.

(ii) Although existing wetland technology is good at removing acidity, it rarely yields a significant decrease in total dissolved solids. In areas where the salinity of inland watercourses is of critical concern, this is a serious limitation of passive treatment technology.

These problems are by no means unique to Spain: they represent potential obstacles to the wider uptake of passive systems in warm, dry climates world-wide, and as such are obvious candidates for further research and development. At the other climatic extreme, under the arctic and sub-arctic conditions which obtain throughout northern Europe, the challenges of maintaining gravity-flow treatment systems under sub-zero conditions must be faced. While successful passive treatment has been piloted in areas where freezing is not perennial, such as the highlands of Scotland (Jarvis and Younger, *in review*) and southern Norway (Ettner, 1999), it is as yet unclear how much of a role passive treatment could have in the remediation of the numerous acidic discharges which lie north of the Arctic Circle in Europe (e.g. Banks *et al.*, 1997). This is a further topic requiring careful research.

One can reasonably conclude that passive treatment as currently practised is best suited to a temperate climate. However, outside of the temperate regions of northern Spain and the UK, passive treatment of mine waters has as yet enjoyed strictly limited uptake in Europe (Table 1). The few applications reported to date have the virtue of novelty, such as a pilot arsenic removal system in southern France, limestone-based systems removing a variety of metal species in Slovenia (Ulrich, 1999), and pilot wetland systems (currently under construction) to remove radionuclides from waters draining old uranium mine sites in eastern Germany. Nevertheless, in view of the widespread incidence of mine water pollution in Europe, the lack of uptake of passive treatment to date is puzzling.

This paper describes a major Research initiative of the European Commission (the executive arm of the European Union (EU)) which was launched in March 2000 in order to address some of the issues identified above, with the ultimate aim of expanding the repertoire of passive treatment and encouraging its more widespread uptake in Europe, not least to address the severe mine water problems which beset many of the eastern European 'accession states' (i.e. countries of the former Soviet Bloc which are currently seeking admittance to the EU).

THE PIRAMID PROJECT: OBJECTIVES

'PIRAMID' stands for <u>P</u>assive <u>I</u>n-situ <u>R</u>emediation of <u>A</u>cidic <u>M</u>ine / <u>I</u>ndustrial <u>D</u>rainage. The project is funded as a collaborative research project between research institutions in five EU Member States (France, Germany, Spain, Sweden and the UK) and one accession state (Slovenia), with the bulk of the direct funding (€1.5M) being provided by the Fifth Framework Research and Technical Development Programme of the European Commission. The total value of PIRAMID (including partner contributions) is estimated to be on the order of €3M. PIRAMID is scheduled to run for the three years ending 28th February 2003.

There are five objectives in the PIRAMID programme:

1. To assemble a European database of experiences with "passive in situ remediation" (PIR) of acidic mine / industrial drainage, covering both surface and subsurface PIR systems.
2. To develop process-based models of PIR system performance, with the purpose of supporting improvement of future designs.
3. To critically evaluate the potential application of PIR in areas of Europe which still do not have the technology.
4. To test in the laboratory and in the field novel approaches to PIR, for other specific contaminants and using novel substrates
5. To develop engineering guidelines for PIR application at new sites throughout the EU

Before discussing how these objectives are being realised in practice it is necessary to define what some of the terminology used above is intended to convey.

DEFINITIONS USED IN PIRAMID

"Passive in-situ remediation" (PIR) is a potentially ambiguous term. In the PIRAMID project it has been formally defined as follows:

> *'Passive in-situ remediation'* signifies an engineering intervention which prevents, diminishes and / or treats polluted waters at source, using only naturally-available energy sources (such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy), and which requires only infrequent (albeit regular) maintenance to operate successfully over its design life

As such, PIR embraces two principal strategies: "passive prevention of pollutant release", and "passive treatment". Subsidiary definitions of these two terms are therefore as follows:

> *'Passive prevention of pollutant release'* is achieved by the surface or subsurface installation of physical barriers (requiring little or no long-term maintenance) which inhibit pollution-generating chemical reactions (for instance, by permanently altering redox and / or moisture dynamics), and / or directly prevent the migration of existing polluted waters.
>
> *Passive treatment* is achieved using constructed (or appropriated, natural) gravity-flow systems, in which all treatment processes use only naturally-available energy sources (such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy), and which require only infrequent (albeit regular) maintenance to operate successfully over their design lives.

Examples of 'passive prevention of pollutant release' include the use of wet or dry covers on waste rock piles (e.g. Gustafsson *et al.*, 1999), the grouting of permeable pathways to prevent rapid migration of contaminants and the use of ground solidification techniques. 'Passive treatment' technologies embrace wetland-type systems (e.g. Hedin *et al.*, 1994; Younger, 1997b), subsurface reactive barriers (e.g. Benner *et al.*, 1997), and an increasing array of gravity-flow geochemical reactors (e.g. Nuttall and Younger, 2000; Younger, 2000). PIRAMID is thus intentionally conceived as a project which can unite the sometimes disparate activities of research teams engaged with particular elements of PIR.

PIRAMID WORKPLAN AND RESEARCH CONSORTIUM

The five objectives listed above are each being pursued by one of five corresponding work packages which together comprise the PIRAMID workplan, i.e.:

Work Package 1: Assembly of a European database of PIR experiences relevant to acidic metalliferous wastewaters.
Work Package 2: Development of process-based models of PIR system performance.
Work Package 3: Evaluation of the potential applicability of PIR to major mining regions of Europe.
Work Package 4: Lab- and field-scale testing of the performance of particular constructed wetland and subsurface reactive barrier systems, and novel PIR substrates (bentonites etc).
Work Package 5: Development of engineering guidelines for PIR implementation.

The research consortium undertaking the work packages comprises the following seven research teams:

(i) The UK team (Co-ordinator). This comprises the Water Resource Systems Research Laboratory, Department of Civil Engineering, University of Newcastle, supported by IMC Consulting Engineers.

(ii) The Catalonian team. This team is led by the Barcelona-based Jaume Almera Earth Sciences Institute of the Consejo Superior de Investigaciones Científicas (CSIC), with sub-contracted support from the Universidad Politécnia de Catalunya and the Instituto Tecnológico Geominero de España (the national geological survey of Spain), based in Madrid.

(iii) The French team. This is based in the Hydrosciences Research Unit of the Centre National de Recherches Scientifiques (CNRS), based at the University of Montpellier 2.

(iv) The German team. This is an alliance between the Universities of Jena and Freiberg in eastern Germany.

(v) The Swedish team. This is a large grouping, previously assembled in the Swedish national mine waste R&D programme 'MiMi' (Höglund, 2000), comprising a multi-disciplinary team of specialists from Luleå University of Technology, Umeå University, Linköping University, Kemakta Consultants Co, the Swedish Geotechnical Institute, and Miljöteknik Bo Carlsson AB (a consultancy firm).

(vi) The Slovenian team, which is the Institute for Mining, Geotechnology and the Environment (IRGO), based at the University of Ljublijana.

(vii) The Asturian team. This comprises the School of Mines at the University of Oviedo, supported by Río Narcea Gold Mines S.A., a successful SME mining company active in northern Spain.

Table 2 summarises the roles of these teams in relation to the five work packages. It is now appropriate to provide further details of the content of the work packages, to clarify the particular issues with which the teams are engaged. In this manner the relationship to previous work, and other international efforts, should become clear.

Table 2 - Roles of the PIRAMID consortium research teams in relation to the five work packages. (Note: "M" indicates a major role in the relevant work package, and "S" a secondary role).

Team	Work Package 1	Work Package 2	Work Package 3	Work Package 4	Work Package 5

UK	M	M	S	M	M
Catalonia (Spain)	M	M	-	M	M
France	M	-	-	M	-
Germany	M	M	M	-	M
Sweden	S	-	M	M	M
Slovenia	S	M	M	M	M
Asturias (Spain)	M	-	-	M	M

TASKS AND APPROACHES

Database of European experiences with mine water PIR (Work Package 1).

The information from which the summary in Table 1 has been produced has been collated into a database formulated in MS Access™, covering information such as system name, location, type, size, and influent and effluent flow rates and chemistry. The database will be updated as new systems are notified to the UK team, and is available for free downloading from the PIRAMID web site.

Development of process-based models of PIR system performance (Work Package 2).

The bulk of performance models for wetland treatment systems to date have been simplistic, either in terms of fluid dynamics or chemical processes (e.g. Kadlec, 2000). Drawing upon a wealth of previous experience in physically-based modelling of ground water flow and reactive solute transport (Saaltink *et al.*, 1998), an integrated simulation code is being developed by the Catalonian and UK teams, capable of simulating coupled surface-subsurface flow and reactive transport, focusing on major biogeochemical processes of the carbon, sulphur and iron cycles which are thought to account for most of the contaminant attenuation in passive treatment systems (e.g. Walton-Day, 1999).

Evaluation of potential for further PIR applications in Europe. (Work Package 3).

Former mining and industrial areas in major mining regions of Europe (particularly the former Soviet Bloc countries of eastern Europe) are large potential growth areas for the application of PIR technology, and as such there is a strong case for evaluating the scope for application of the technology in those regions. Added to this are the very real issues of PIR viability under hot or cold climatic extremes, as discussed above. To address these issues, a two-phase programme of work is underway. The first phase is largely a desk study of hydrogeological and mining information. In the second phases, typical scenarios of short- and long-term pollutant release from representative mine systems will be evaluated using a modified version of a pre-existing numerical model code which simulates hybrid conduit-continuum flow systems (Younger *et al.*, 1997). For the case of uranium mine drainage, the model will include a reaction module for metal release from ore impregnated fracture surfaces, allowing for reaction kinetics (diffusion/surface reaction limitations), the conceptualisation of an upscaling procedure, and sensitivity studies to determine dominant parameters. Test simulations for specific sites within the region will be made. The aim will be to produce a well-documented (though not exhaustive) dossier of contaminated mining and allied sites representative of the range of acidic and / or metalliferous drainage problems commonly encountered.

Lab- and field-scale testing of PIR systems, and novel PIR substrates (Work Package 4).

The largest single work package, this represents the experimental core of PIRAMID. The work takes full advantage of the existence of so many PIR systems in the UK, and augments routine monitoring data supplied by site owners (the UK team are themselves owners of several systems; Younger, 1998b; Jarvis and Younger, 1999) with detailed field and lab experiments on the biogeochemical processes occurring in wetland substrates and emergent vegetation. Similar studies of a natural wetland in Sweden will be made, to help inform the issues of PIR applicability in cold regions. An existing arsenic oxidising system in southern France, and arsenic-treatment wetland systems in Spain (Ordoñez *et al.*, 2000) will also be carefully analysed. A particular focus in northern Span will be on the feasibility of PIR approaches for cyanide rich effluents from gold mine processing effluents. In eastern Europe, the focus will be on the potential use of PIR for uranium mine drainage. A major effort in relation to subsurface reactive barriers is underway at the Aznalcóllar site in southern Spain, where both hydraulic and tracer tests will be made before and after actual barrier emplacement to evaluate chemical and hydraulic behaviour at a highly heterogeneous real site. These will be verified by means of two holes drilled inside the barrier. Lessons learned from these lab and field experiments will be used to inform both the development of engineering guidelines and the finalisation of plans for PIR applications elsewhere.

Development of engineering guidelines for PIR implementation (Work Package 5).

Drawing upon the wealth of practical experience of IMC Consulting Engineers, engineering details (drawings and other data) obtained for pre-existing PIR systems in the UK and Spain during Work Package 1 will be examined, and common elements of design and construction practice noted. Consideration of analogous engineering problems will be used as the basis for developing a critique of existing approaches, upon which revised guidelines for PIR system design and construction will be based. (The hypothesis here is that since many PIR systems have been developed by scientists with little background in engineering, there may well be scope for simple but effective improvements in design and construction practices). As the results of the Work Package 2 modelling exercises and the Work Package 4 experiments become available, the engineering guidelines will be revised once more to include methods for incorporating new materials and processes into PIR system design. The guidelines will be available for down-loading from the PIRAMID web site in February 2003.

CONCLUSION

Passive treatment of mine waters was introduced to the UK in the mid-1990s and is now spreading to mainland European countries. To facilitate the wider uptake of the technology, the PIRAMID project is addressing biogeochemical, hydrogeological and engineering aspects of passive treatment by means of collaborative research between six European countries. Dissemination of PIRAMID outcomes will be primarily via the project web-site at http://www.piramid.org

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