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# REVIEW OF SELECTIVE SEPARATIONS OF COBALT, URANIUM, ZINC, NICKEL AND ASSOCIATED CONTAMINANTS FROM VARIOUS PROCESS STREAMS

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**Abstract**

IBC Advanced Technologies' Molecular Recognition Technology (MRT) SuperLig® products selectively and rapidly bind with target metal ions to remove them from solution even at the mg/L concentration level. The MRT process can produce a high purity separation product of maximum added value at low cost. This paper discusses applications for MRT in the cobalt industry, including removal of cadmium, copper, lead, and nickel. Additional separations of interest to the African mining industry will also be discussed, including those involving uranium, iron, bismuth, and zinc.

## 1.    Introduction

Cobalt and Zn process streams contain a variety of metal contaminants including Cd, Cu, Pb and Ni. Uranium feed solutions can contain significant amounts of Fe, Cu, Co and Ni. An important challenge in processing primary metal ores is the selective separation, recovery and disposition of the associated metals. These metals are often found in small quantities which compounds the problem since traditional separation methods such as solvent extraction (SX), ion exchange (IX) and precipitation become increasingly less effective as the concentration of the metal to be separated decreases toward the mg/L level. Metals are of growing importance in the world's economy. Specialty metal uses are found in catalytic, energy, pollution abatement, electronic and structural material areas. As purity requirements become more stringent and environmental concerns grow, the need for more effective and environmentally friendly separation procedures increases. In the base metal industry, these improved procedures are needed in metal production from primary ores, in metal purification by removal of trace impurities to the mg/L concentration levels and in the recovery of trace metal impurities in concentrated form for resale or disposal in an environmentally friendly manner.

IBC has unique products, trade named SuperLig®, which use proprietary Molecular Recognition Technology (MRT) to carry out separations. SuperLig® products have proven selective metal separation properties that are effective at low (mg/L to µg/L) concentration levels where traditional separation techniques are ineffective. The MRT process is discussed in Section 3.

In this paper, the need for more effective and environmentally friendly production, recovery and disposition methods for the metals mentioned in Section 1 is presented. The MRT process is then described with examples of the use of MRT in the base metal and uranium industries to (1) recover primary metals in ore processing, (2) remove impurities to the mg/L or lower concentration levels in process solutions, (3) recover and concentrate impurity metals for resale or safe environmental disposal and (4) replace traditional technologies by MRT in process flow sheets.

## 2.      Need for More Effective and Environmentally Friendly Separation Methods for Metals

The need for more effective and environmentally friendly separation methods is driven by several factors.  Firstly, modern electronic, energy, super strength material and catalyst uses have increasingly stringent metal purity requirements.  Attaining these requirements involves the removal of impurities to concentration levels of mg/L or below.  Secondly, increasing attention is being given worldwide to maintaining environments free of metal contamination [1-3].  As this movement spreads, resulting in legal constraints on the disposal of end-of-life (EOL) and low-level waste materials, the need for more cost-effective and efficient separation methods increases.  Thirdly, improved recycling procedures for low concentration levels of metals from EOL and low-level waste materials are needed to insure sustainable supplies of many critical and precious metals. Without effective recycling, some metal ores (e.g., Zn, Cu, Pt) could become scarce within decades [4].

In the material that follows, advantages and disadvantages of traditional metal separation methods are given, concerns about the recovery of several toxic metals found in metal processing streams are discussed and the desirable features of a separation system capable of meeting the demand for highly purified metals in a cost-effective and environmentally friendly manner are presented.

### 2.1.    Traditional Methods

In Table 1, several traditional separation methods are listed together with advantages and disadvantages of each.  Current pyrometallurgical and hydrometallurgical recycling and recovery methods, such as smelting, IX, SX, and precipitation require that dilute quantities of target metals be concentrated, resulting in potential deleterious effects on the environment.  Smelting processes result in the emission of respirable metal-containing

**Table 1.** Some traditional separation methods

| Procedure | Basis | Advantages | Disadvantages |
|---|---|---|---|
| Smelting | Formation of a high-temperature melt from which metals can be recovered selectively | Applicable to a wide variety of metals | Energy intensive, emission of hazardous particulates, environmentally unfriendly, expensive transportation costs usually required, treatment of low-level wastes not cost-effective, long inventory time (months), large space requirements |
| Precipitation | Precipitation of target metal with added reagent | Inexpensive reagents | Separation and disposal of precipitate, co-precipitation, new contaminants added, decreased concentration of target species, limited selectivity option, low selectivity |
| Ion Exchange | Exchange on a resin of a bound species by the target species | No organics required, no loss of resin to environment | Selectivity based on ion charge, new contaminants added, decreased selectivity with decreased concentration of target species, large space requirements, hydrophobic support, slow kinetics |
| Solvent Extraction | Selective transfer of target species to a second immiscible solvent | Some selectivity for target species by host extractant | New contaminants added, large space requirements, organics contaminate aqueous stream, hydrophobicity requirements for ligand can add to cost and development, slow kinetics |

particulates, noxious gases (e.g., $SO_2$, $NO_x$, $PO_x$), greenhouse gases and toxic metals (e.g.,Cd, Hg, Pb, As). Traditional hydrometallurgical and precipitation methods can result in solvent loss to the environment and introduction of reagents during processing that produce potential new pollutants. Incremental improvements have been made to these

processes, but the potential environmental problems associated with their use remain. The inadequacy of present separation methods to meet needs of modern technology for high-metal purity and removal of mg/L quantities of metal impurities has been noted by Gedgagov [5].

## 2.2.    Recovery of Toxic Metals

The toxic metals Cd, Pb, and Hg are used in electronics and other industries and thus appear in EOL products and in many waste streams. Recovery of toxic metals from these sources is low [1-3]. They are present as minor constituents in many primary ores where they must be removed in processing in order to obtain high-purity target metal products. Traditional separation methods are not adequate for removal of these toxic metals to the concentration levels required from primary ore processing, EOL materials, or low-level metal wastes. The removal and recovery of these toxic metals is urgent since their negative health effects on humans is severe and well documented [6]. Significant human health and environmental dangers can result if EOL and low-level metals are consigned to waste dumps and landfills because the toxic metals in these products leach out, enter the environment, move up the food chain, and eventually enter the human food supply. In the case of industrial processing of metal ores, there is an economic incentive to remove impurity metals, such as Cd from Co streams, in order to obtain Co of high purity. However, the economic incentive is usually lacking in the recovery of small quantities of toxic metals from EOL materials or from low-level metal waste streams which usually are consigned to landfills. The seriousness of this problem has been noted [1-3]. As will be discussed in Sections 3 and 4, IBC's MRT process offers an effective means for environmentally friendly toxic metal recovery at concentration levels of mg/L or less.

## 2.3.    Desirable Features of an Effective Separation System

There is a need for a new and environmentally friendly approach to the problem of separating metal impurities from low-level metal wastes. In Table 2, desirable features of an effective separation system are given. MRT successfully incorporates these features into separation systems that greatly enhance the ability to carry out separations at the mg/L concentration level in a clean, rapid and cost-effective way.

## 3.    Molecular Recognition Technology (MRT)

MRT is a highly selective, non-ion exchange system, using specially designed organic chelators or ligands that are chemically bonded to solid supports such as silica gel or polymer substrates. The MRT process [7,8] utilizes "lock and key," or "host guest" chemistry as a basis for its high selectivity. The solid phase system consists of the small

**Table 2.** Desirable features of an effective separation system[a]

| | |
|---|---|
| 1. | Have sufficient specificity for the target species even if present at mg/L concentration levels in the presence of high concentrations of other similar species. |
| 2. | Have sufficient specificity for a given oxidation state of an element when the element has multiple oxidation states. |
| 3. | Have sufficient selectivity for the target species when it is in a difficult matrix, such as strong acid, strong base, $F^-$/HF, redox agents, other complexing agents and high solute concentrations. |
| 4. | Be capable of operation without adding potential contaminants, such as solvents, replacement ions and precipitants. |
| 5. | Be capable of removing target species to sufficiently low target concentrations. |
| 6. | Be capable of handling large solution volumes at rapid-flow rates. |
| 7. | Have rapid separation kinetics for diffusion, host-guest interaction and host-guest dissociation. |
| 8. | Have adequate longevity due to resistance/stability to matrix chemical effects, Including intense nuclear radiation, acid/base, redox and other chemical reactants. |
| 9. | Be capable of automation in a continuous mode. |
| 10. | Be capable of concentrating desired species by large factors leading to rapid and efficient recovery of highly purified products that can be marketed or disposed of in an environmentally safe manner. |
| 11. | Be capable of removing impurities from waste streams producing an aqueous effluent that can be safely discharged into agricultural or culinary water supplies. |
| 12. | Have low energy requirements. |
| 13. | Have zero greenhouse gas emissions. |
| 14. | Have a low carbon footprint |

[a]Reprinted in part from [7] with permission

particles to which the selective ligand is covalently attached (SuperLig®). The SuperLig® product is packed into fixed-bed columns that, in commercial operation, can be built in skid-mounted modular form, and can be fully automated for continuous operation. The feed solution is passed through the column and the target ion is removed from the solution.

SuperLig® products are designed to bind selectively with ions based on multiple parameters such as size, coordination chemistry, and geometry. In contrast, conventional separation methods such as precipitation, IX, and SX generally recognize differences between ions based only on a single parameter, for example, charge, solubility or size. SuperLig® products can bind ions even when the ions are present in highly acidic or basic solution and/or in solutions containing high concentrations of competing ions. The MRT process exhibits high selectivity, high binding factors and rapid reaction kinetics, resulting in a very efficient separation. The simple elution chemistry uses small volumes of eluate. Thus, dilute solutions are concentrated and can be treated to produce, with minimal

environmental impact, either marketable products of high added value or pure products that can be reused or disposed of in an environmentally safe manner. The high selectivity, high loading capacities and rapid loading and release kinetics of SuperLig® products result in substantially lower capital and operating costs in commercial scale operations than are found for other technologies, such as IX, SX, and chemical precipitation. Since relatively small quantities of the appropriate SuperLig® product are required, the scale of the installation can be smaller, solution wash and elution chemical requirements and volumes are substantially less, and high feed solution flow rates are possible. Higher efficiencies are attained due to the single-pass, high percentage, quantitative removal of the target species. SuperLig® products have a long life expectancy and do not introduce contaminants into the separation process.

MRT can be used to accomplish metal separations at very low mg/L concentration levels that are not possible using traditional technologies [7,8]. The effectiveness of other technologies decreases sharply as the metal content in the feedstock decreases toward the mg/L concentration level. The commercially pure products produced from such feed stocks using MRT can be sold or recycled. This is an important factor from the standpoints of cost and sustainability. A wide choice of eluent formulations is usually available to ensure compatibility with particular plant requirements. Highly concentrated eluent solutions can be produced from which the simple recovery of a high purity, high value-added product is possible. The use of MRT has applicability to the removal of a wide range of impurities from various feed stocks. MRT is a well-established technology used in both the base and precious metals industries.

## 4.    Applications of MRT in Separations of Interest in Base Metal and Uranium Processing

The following examples illustrate the broad range of metal separations at the mg/L concentration level that are possible using MRT. The ability to achieve high selectivity at the mg/L concentration level in the presence of multiple competing species at the g/L concentration level is extremely important both from an economic standpoint and from an environmental perspective. Using MRT, there is no need to first concentrate the target metal, thereby avoiding energy intensive, toxic, and environmentally unsound processes that would otherwise be required. Examples are now given of the use of MRT in separations of interest to the base metal and uranium industries.

## 4.1.    Maintenance of a Specified Cadmium Level in a Cobalt Electrolyte Matrix [9]

Cobalt metal specifications are stringent. One of the important impurities in Co electrolyte solutions is Cd. SuperLig® 177 is capable of removing Cd and thus, meeting the required specifications for Grade A Co [9]. This product was tested for its ability to remove Cd

(~6mg/L) from a Co electrolyte solution containing 60 g/L Co. The Co electrolyte solution also contained Mg, Al, Si, Ca, Mn, Fe, Ni, Cu, Zn and Pb. High Cd loadings were obtained with the SuperLig® product, that is, 2.9 g/L Cd from a feed solution containing ~6 mg/L Cd giving an upgrading ratio of 480. The amounts of Co and the matrix elements in the eluent were nearly non-detectable making the selectivity factor (SF) for Cd over each of these elements very large. For example, log SF at pH 2 for Cd over Co, Mg, and Mn (Figure 1) were 4.48, 5.41, and 3.55, respectively. Similar log SF values were found at pH 4.
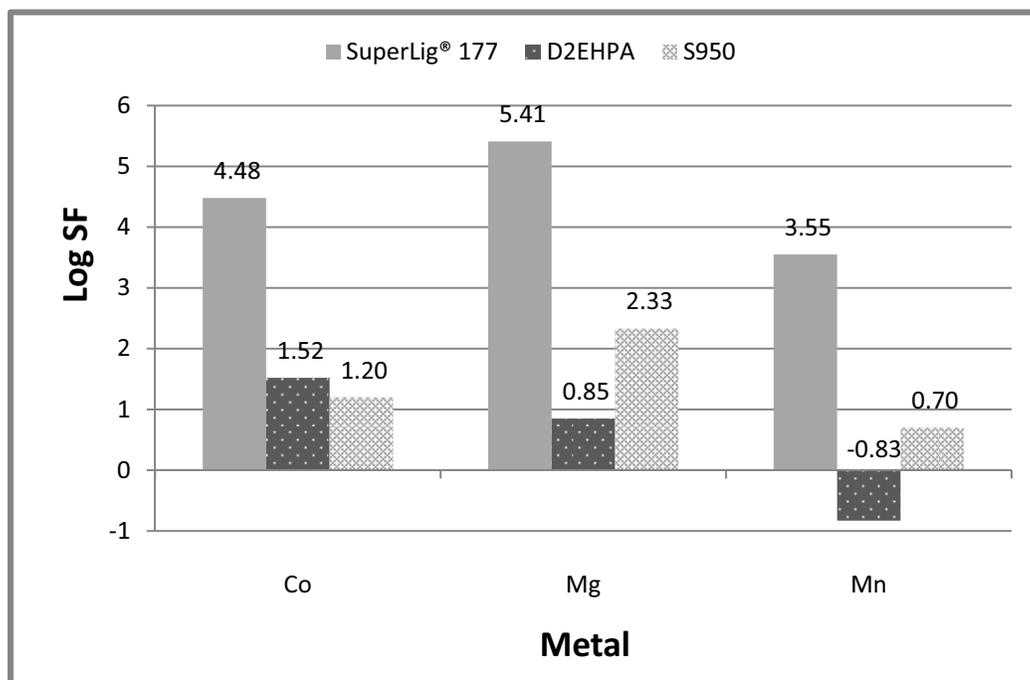


**Figure 1.** Plot of the log of the selectivity factor (log SF) vs metal for the separation by SuperLig® 177, D2EHPA and S950 of cadmium from cobalt, magnesium and manganese. Experimental conditions are given in the text.

The ability of SuperLig® 177 to selectively remove Cd was found [9] to be much greater than that of either the solvent extraction agent di-2-ethylhexyl phosphoric acid (D₂EHPA) or the adsorption agent amino-methyl phosphoric acid resin (Purolyte S950). The log SF values for these reagents at pH 4 for Cd over Co, Mg, and Mn (Figure 1) were 1.20, 2.33, and 0.70 respectively, for Purolite S950 and 1.52, 0.85, and -0.83 respectively, for D₂ EHPA at pH 2.5. These log SF values were much lower than those for SuperLig® 177 (Figure 1), which is clearly the superior reagent for Cd removal from Co electrolyte. The Cd removed by SuperLig® 177 is recovered directly as a pure product which can be sold to help defray the costs of the separation.

## 4.2.  Maintenance of a Specified Bismuth Level in Copper Electrolyte Solutions [10]

Bismuth is often found in Cu ores.  In the manufacture of pure Cu, the Bi concentration level must be maintained at or below a specified level, otherwise the resulting Cu is brittle and not suitable for modern high-tech applications.  SuperLig® 83 is able to maintain this required level by removing Bi from a Cu electrolyte bleed stream.  IBC's Bi effective recovery process has been recognized for its innovativeness [11], and is used worldwide to maintain Bi impurity concentration levels at target 150 to 800 mg/L in Cu tank house electrolytes [10].   The Bi concentration level in the Cu electrolyte is monitored continuously and the Bi removal system is used automatically as needed to maintain a pre-determined Bi concentration level.  After  Bi is loaded, it is eluted from the MRT column producing a highly concentrated multiple g/L bismuth sulfate solution.  Following a liquid/solid separation, the pure bismuth sulfate can be marketed to chemical producers, which helps to offset the cost of its removal.

## 4.3  Uranium Removal from an Iron, Cobalt, Nickel Matrix [12]

The use of SX and IX resins is the technology of choice for extraction of U from clarified mine leach solutions, leached pulp and slurries [13,14].  The application of MRT to U extraction from these feed streams, as well as to evaporation ponds and waste streams, offers a viable highly competitive alternative to SX and IX resins.  The extremely high selectivity of SuperLig® products makes MRT an excellent candidate to dramatically simplify the flow sheet for U recovery from these solution matrices. The MRT process can selectively separate the U directly from the feed solution and produce a concentrated, high-purity U product.  A summary of many of the key benefits offered by MRT in this separation is available [12].

In one experiment, U was removed from U feed solutions containing significant amounts of Fe, Cu, Co, and Ni in a sulfate matrix [12].  SuperLig® 171 was used for the U separation. The U species separated was $U(SO_4)_4^{2-}$.  The feed solution, containing 117 mg/L U and the aforementioned metals, was passed through a column loaded with SuperLig® 171.  Uranium was removed from the feed solution by the column-bound SuperLig® 171 to detection limits of 5 mg/L.  Following washing of the column to remove residual feed solution, the U was eluted using 8 M $H_2SO_4$.  In the resulting eluent, concentration levels of Co, Ni, Cu and Fe were <1 mg/L.  Approximately 17 bed volumes were required for the complete elution of the U.  The eluted U was concentrated in pure form.  The large-scale system needed to carry out this separation procedure is readily engineered and fully automated providing significant advantages over conventional procedures [12].

## 4.4.     Cobalt Removal Chemistry Incorporating Iron (III) as a Pseudo-Catalyst [15]

SuperLig® 138 binds both Co(II) and Co(III).  However, SuperLig® 138 has much greater affinity for Co(III) and is selective for this species over bivalent metal ions.  Experimental tests with highly concentrated Zn solutions containing impurity ions have shown that Co is polished to either trace or below detection concentration levels from such solutions only when bound as Co(III).

This result is in agreement with the apparent formation constants (K) of complexation of SuperLig® 138 with different metal ions, as given in Table 3.  The apparent K value is defined as follows:   $M^{n+}$(aq) + L(ligand) = L-$M^{n+}$ (L = loaded ligand on SuperLig® column), K = [L-$M^{n+}$]/[$M^{n+}$][L].

**TABLE 3.**  Estimated apparent log K values for metal ion-Superlig® 138 complexation

| Species | Log K |
|---|---|
| $Cu^{2+}$ | 20.0-21.5 |
| $Co^{2+}$ | 18.0 |
| $Co^{3+}$ | 30.0 |
| $Ni^{2+}$ | 19.0 |
| $Zn^{2+}$ | 15.2 |
| $Mn^{2+}$ and $Mg^{2+}$ | None |

Considering the relative log K values of $Zn^{2+}$, $Co^{2+}$, and  $Co^{3+}$, the removal of $Co^{2+}$ at mg/L concentration levels would not be possible at high Zn concentrations (e.g., 150 g/L), whereas $Co^{3+}$ would bind preferentially even at  extremely  low  concentrations  (<0.1 mg/L).   However, Co(III) does  not exist to any significant level in the normal oxidation-reduction potential (ORP) ranges of solutions without a strong Co(III) chelant present. Hence, the only way to bind Co to SuperLig 138 as Co(III) is to first bind Co(II) to the ligand on SuperLig®138 and then oxidize the Co(II) to Co(III).  This is possible since Co(II) binds to the resin to a significant but not polished degree in  solutions of  high  Zn concentration.   There is ~ 20-30 mg/L Co to be bound to the resin  and oxidized in the test solution (which contains sufficient $O_2$ to perform the oxidation). However, this oxidation can be very slow kinetically if a more rapid oxidizer is not present to speed up the process. Fe(III) is an excellent choice for the oxidizer.  The Fe(III) is both a rapid oxidizer and the Fe(II) produced is readily re-oxidized by $O_2$ to Fe(III), if needed.  Hence, the Fe(III) can be considered to act like a catalyst in that it speeds up the reaction and is eventually returned to its starting state.  This work illustrates the versatility of the MRT approach.  By altering the chemistry, SuperLig®-bound Co(II) is oxidized to Co(III) using Fe(III).  The Co(III) has  a much higher log K value for complexation  to  SuperLig® 138 than any of  the other

metal ions present, including Co(II). The Co(III) remains bound to the SuperLig® 138 on the column as the residual Zn feed stream containing the remaining impurity metals is washed out of the column. Cobalt(III) is then eluted from the column using 6 M HCl and 0.25 M FeC1$_2$ at ~ 25 ºC. Using this procedure, the Co concentration in a feed stream can be reduced to <0.1 mg/L from feeds with 1-50 mg/L Co and to slightly higher Co concentration levels from feeds with higher Co concentrations. The eluted and concentrated Co can be recovered in a pure form for re-use or resale after HCl distillation and Fe precipitation.

### 4.5. Extraction and Polishing of Nickel from a Cobalt-Bearing Feed Stream in a Nitric Acid Matrix [16]

This MRT process has been installed at a major international secondary Co refiner and manufacturer of Co and Ni chemicals. In this application, SuperLig® 199 is used to extract and polish Ni from a Co feedstock containing approximately 150 g/L Co in an HNO$_3$ matrix. The Ni concentration in the feed stream is <10 g/L. The solution pH is ~ 1. SuperLig® 199 has a high selectivity for Ni over Co and is most effective for Ni and Co separations when the Co/Ni ratio is <200/1. If significant amounts of Cu are present in solution, the solution must first be pretreated for removal of Cu.

A complete cycle consists of the following sequential phases: (1) Loading Phase – the Ni$^{2+}$ in the feed solution is loaded onto the column-bound SuperLig® 199. (2) Pre-Elution Wash Phase – the column is washed with 0.1 M HNO$_3$ and 0.5 M HNO$_3$ to remove residual feed solution. A portion of the wash is recycled. (3) Elution Phase – The Ni$^{2+}$ is eluted from the SuperLig® 199 product in the column with 4 M HNO$_3$ at ~ 25 ºC, forming a high-purity Ni (NO$_3$)$_2$ product solution. A portion of the eluent solutions is recycled. (4) Post-Elution Wash Phase – the column is washed with water. The cycle then begins again at sequence (1).

### 4.6 MRT Applied to the Purification of a Variety of Cobalt Streams [17]

IBC has numerous SuperLig® products that can be used in the separation and purification of metal components from various Co streams. In Table 4, several applications are listed together with the SuperLig® product applicable to the particular process. The examples in Table 4 illustrate the numerous applications of SuperLig® technology to difficult separations of importance to the Co industry. The separations can generally reduce the impurity metal concentration levels to <1 mg/L in the feed solution. The metals can be

**Table 4:** Summary of MRT separations involving cobalt
and several impurity metals

| Application | SuperLig® Product |
|---|---|
| Extraction and polishing of Fe from a Co stream in an $H_2SO_4$ matrix | SuperLig® 48 |
| Cd removal from Co electrolyte | SuperLig® 177 |
| Extraction and purification of Cu from a Co process stream | SuperLig® 77 |
| Extraction and polishing of Ni from a Co stream in an $H_2SO_4$ matrix | SuperLig® 241 |
| Extraction and polishing of Ni from a Co stream in an $HNO_3$ matrix | SuperLig® 199 |
| Co-extraction of Cu, Fe, and Ni from a Co stream in an $H_2SO_4$ matrix | SuperLig® 176 |
| Co-extraction of Co and Ni from an Ni laterite ore process stream with subsequent separate elutions for Ni and Co | SuperLig®138 |
| Separate extractions of Ni, Cu, and Fe from concentrated acidic Co/base metal solution with separate elutions producing pure salt products | Solution pH 1<br>Cu: SuperLig® 86<br>Fe: SuperLig® 14<br>Ni: SuperLig® 199<br>Co: SuperLig® 86 |
| Separate extractions of Cu/Fe, Ni and Co from concentrated acidic Co/base metal solution with separate elutions producing pure salt products | Solution pH 2<br>Cu/Fe: SuperLig® 145<br>Ni: SuperLig® 199<br>Co: SuperLig® 138 |

recovered from the eluent in concentrated form for resale or for safe disposal in an environmentally friendly manner. In all cases, the SuperLig® process can be incorporated into an appropriate flow sheet where it is automated. The separations are effective in complex matrices, in highly acidic solutions, and in the presence of metal species having similar chemistry. The versatility of the MRT process is evident in these separations. Each of the applications has been tested at commercial scale. Details of each process, including flow sheets, are available [17].

## 4.7. Toxic Metal Separations

IBC has SuperLig® products capable of making separations of Cd, Hg, and Pb at the mg/L to the g/L concentration level. These metals are found as trace constituents of sulfide ore bodies [6] and often need to be separated from processing streams to insure the purity of

target metals.  They are also constituents of electronic devices and rechargeable batteries [1-3].  Separation of Cd from Co feed solutions has been discussed in this paper (Section 4.1).  Separation of Hg from an $H_2SO_4$ stream using SuperLig® 8 has been described [18].  SuperLig® products for Pb separations are also available.  SuperLig® 177 will remove trace amounts of Pb, if present, with Cd as described in Section 4.l.  SuperLig® 50 and SuperLig® 62 are products that are highly selective for Pb over a wide range of other metals over the entire pH range from highly acidic to highly basic solutions.

## 5.      Advantages of MRT Processes [17]

Important advantages of MRT over traditional separation technologies are presented in Table 5.

**Table 5.**  Key advantages offered by MRT separation plants [17]

| Advantage | Resulting Benefit Provided by MRT System |
| --- | --- |
| Extremely high selectivity for target ion | High purity, concentrated eluent products are produced |
| Effective at any target ion concentration | The MRT process is used to remove target ions present at concentration levels of mg/L to µg/L |
| High metal recovery in single solution pass through | Minimizes cost of metal recycle |
| Minimal metal losses in process | Additional metal sales revenue and reduced costs |
| High feed solution flow rates | Increases unit throughput capacity |
| Extremely rapid processing time | Dramatic reduction in process inventory, resulting in substantial increase in annual metal throughput and consequent increased revenue and cash flow |
| Greatly simplified process | Lower capital cost, reduced space requirement, and minimal maintenance |
| Full automation possible | Minimal manpower requirement |
| Long life, multi-cycle use for the SuperLig® product | Ensures economic benefits for the MRT process |
| Wide range of pH capability | Wide variety of feed solutions can be treated |
| No transfer of impurities to the solution being treated | Simplifies process flow sheet and maximizes product purity |

## 6.  Conclusions

High purity metals are in great demand for use in catalytic, energy, pollution abatement, electronic and structural material areas.  IBC's MRT SuperLig® products offer a highly selective, environmentally friendly and rapid means of separating, recovering and

concentrating impurity metals present at concentration levels of mg/L or less in process feed solutions. The MRT process can be automated and incorporated into existing metal processing plants. MRT has significantly lower capital and operating costs and has important environmental advantages over traditional separation and recovery technologies such as smelting, SX, IX and precipitation. This paper has described the MRT process using several examples involving the base metal and uranium industries. Examples include Cd removal from a Co electrolyte matrix; Bi removal from a Cu electrolyte solution; U removal from an Fe, Co, Ni matrix; Co removal from a base metal matrix using an Fe(III) redox reaction; Ni removal from a Co-bearing feed stream; separations involving Co and several impurity metals; and toxic metals separations. Advantages and benefits offered by MRT separation plants have also been described.

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*S R Izatt, N E Izatt, R L Bruening*

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