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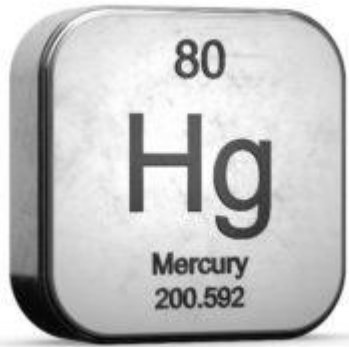
MINAS DE ALMADÉN Y ARRAYANES, S.A.,S.M.E.



**REMEDIATION OF MERCURY CONTAMINATED SITES.
THE CASE OF “CERCO SAN TEODORO” ALMADEN
DUMP AND THE OLD MERCURY METALLURGY
FACILITIES OF THE CERCO DE ALMADENEJOS**

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INTRODUCTION. MERCURY



Hg is a constitutive element of the earth that exists naturally in the environment in a variety of ways, the most frequent being cinnabar ore (HgS). Hg has been a highly valued metal since time immemorial for its special characteristics.

However, the evidence of the damage it causes to the environment and to humans has made it subject to regulation by international organizations, undertaking measures to control their production, emission, uses and management of their waste in order to protect human health and the environment, such as **Strategy Concerning Mercury**, at a global level, the **Minamata Convention**.



INTRODUCTION. BACKGROUND



MAYASA is the state-owned company that had exploited and marketed these resources since time immemorial.

LOCATION / SITUATION

Almadén is the region with the largest mercury deposit in the world

The Almadén mine has been dedicated to the exploitation and production of mercury for more than 2000 years, being one of the oldest mines in the world.



INTRODUCTION. BACKGROUND

Nevertheless, in recent years, market conditions and environmental legislation promoted by the European Union have marked the pace of mining development:

- ☐ Year 2001
Mercury mining activity gradually slowed
- ☐ Year 2003
Primary mercury metallurgy was stopped
- ☐ The mercury exports were banned in March 2011 by European regulations.



MERSADE project

INTRODUCTION. BACKGROUND

In this context, MAYASA proposes the following objectives:

RESTORATION OF ITS HISTORICAL-CULTURAL HERITAGE.

The transformation of the mining-metallurgic installations into a cultural space for public visits, which has become known as THE ALMADEN MINING PARK

www.parqueminerodealmaden.es



Saint Aquilino headframe . XX century

ENVIRONMENTAL RESTORATION; to reverse the exploitation effects that had affected the location for more than two thousand years

ENTREDICHO MINE



ENVIRONMENTAL RESEARCH AND TECHNOLOGICAL DEVELOPMENT, by the creation of the **Mercury Technological Center**



REMEDIATION OF MERCURY CONTAMINATED SITES.PRACTICAL CASES



Reconditioning of the “Cerro de San Teodoro” dump



DESCRIPTION

This waste heap contains deposits of waste from the mining operations as well as slag from the metallurgical processes accumulated through the centuries.

The volume of the waste heap is at present close to 3,5 million tons, covering 10 hectares

Reconditioning of the “Cerro de San Teodoro” dum



DUMP GEOMETRIC CHARACTERISTIC

OCCUPIED AREA (ha)	9,1
TOP AREA (ha)	4,9
SLOPE AREA (ha)	4,2
WASTE AMOUNT (t)	3,500,000
MAXIMUM HEIGHT (m)	58,7
MEDIUM SLOPE ANGLE	36º
PERIMETER (m)	865

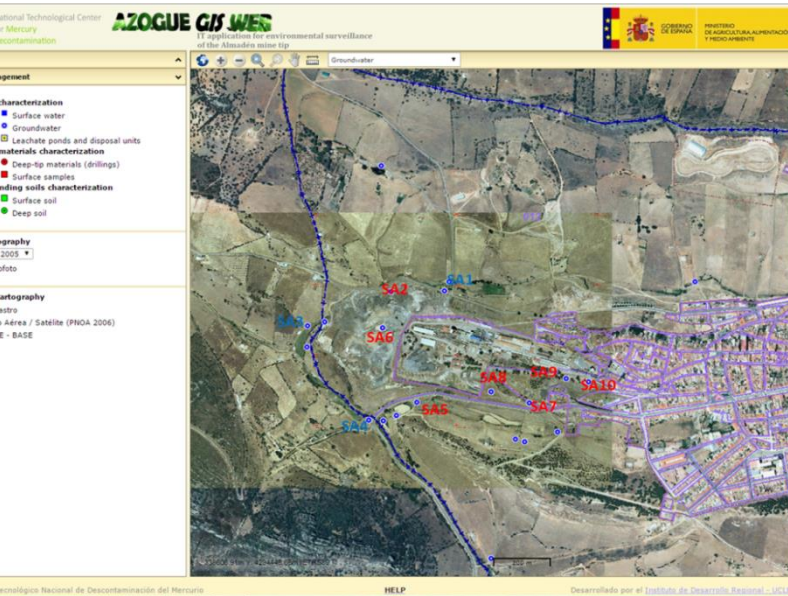
ENVIRONMENTAL IMPACT ASSESSMENT

- **HYDROGEOLOGIC CONTAMINATION.** Riverbed and water contamination by run-off and lixiviated from dump
- **ATMOSPHERIC CONTAMINATION.** Re - suspension of dust downwind and mercury evaporation from the dump surface
- **GROUND OCCUPATION.** Contamination of nearby lands by dust dispersion
- **GEOTECHNICAL RISKS.** High risk of landslide and also a risk of rocks falling
- **MORPHOLOGY AND LANDSCAPE.** Modification of visual and chromatic landscape



CHARACTERIZATION

Characterization of groundwater



By an inventory of water points, water catchment points and springs in the area, and designed a set of ten boreholes around the site to drill all structures and formations of hydrogeological or hydrochemical interest.

AZOGUE GIS WEB Geographic Information System which store the environmental information about the restoration project of the Almaden dump. More information in this web site.
<http://www.ctndm.es/proyectos/1.php>

Characterization of surface water

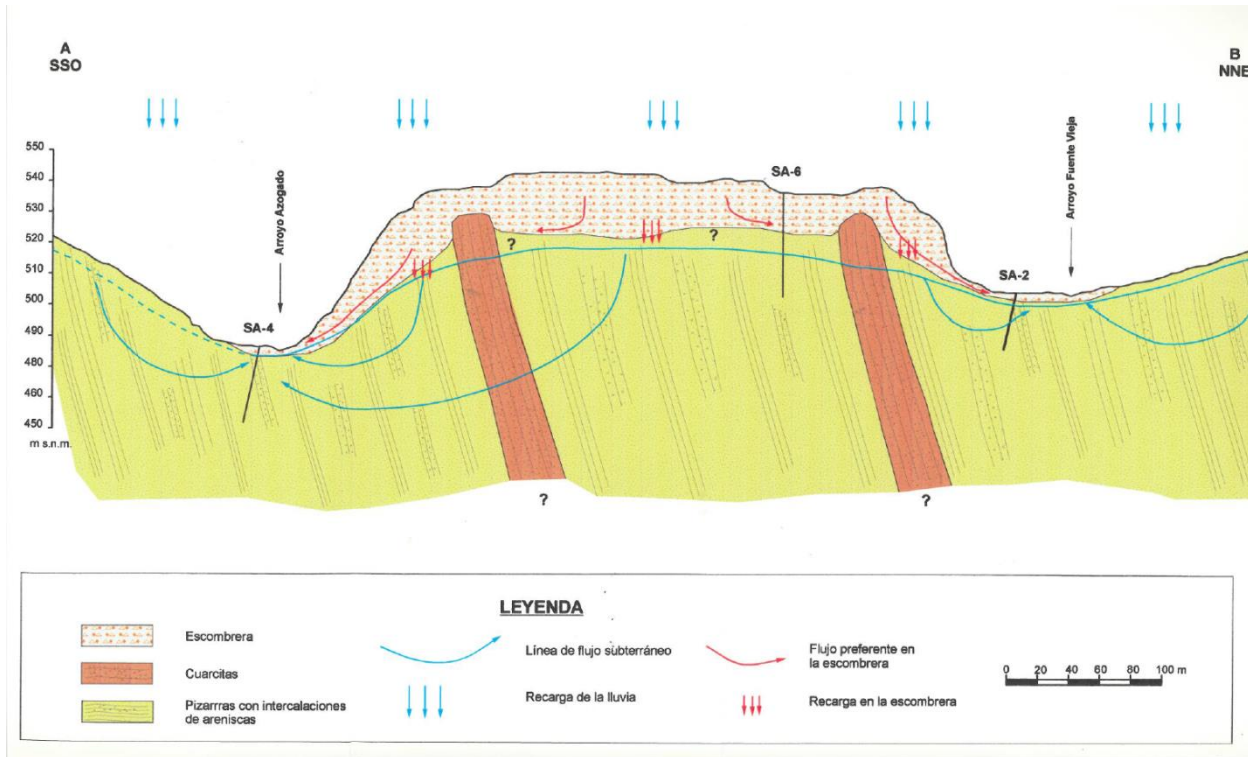
To determine the dispersal of contamination by leaching from the site and the impact of the contaminated site on surface water, we made some analysis upstream of the supposed mercury point source and downstream of all the possible points of exposure.

ALMADEN DUMP

- **River network:** little flow and low slope.
- Conditioned by climate
In summer, **intermittent flow**



CHARACTERIZATION



The hydraulic characterization showed the permeability of the dump is much higher than that of the land on which is located, the water table is very close to the ground surface (about 3 or 4 m). This shows that the dump is on the ground water of the site. There is a radial flow to north, west and south. Despite the near proximity of the mine (that it is seven hundred meters deep), the water table remains in its position, it shows the low permeability of the ground.

The water comes only from the rain and goes through the dump and it is discharged to the surrounding streams: in the north and west, the Fuente Vieja stream and in the south, Azogado stream.

ALTERNATIVE ACTIONS

- MOVEMENT AND CONSTRUCTION OF A NEW SAFETY DUMP
 - High environmental and economic impact
- DUMP FORMING AND WATERPROOFING
 - Good hydrogeological conditions of the dump



ENCAPSULATION OF THE DUMP

MAIN WORKS: **ENCAPSULATION OF THE DUMP**

AIMS:

- STABILITY AND LANDSCAPE INTEGRATION WITH THE DUMP AND THE SURROUNDINGS
- SECURING WATERPROOFING, AND ISOLATION FROM ITS SURFACE.

PHASES

1. DUMP FORMING

Aims:

- Remodel the slopes and the capping plate of the dump
- Stabilizing their conditions
- Earth filling of 493,582 m³ of material



“arco de San Teodoro” dump

2. DUMP SEALING:

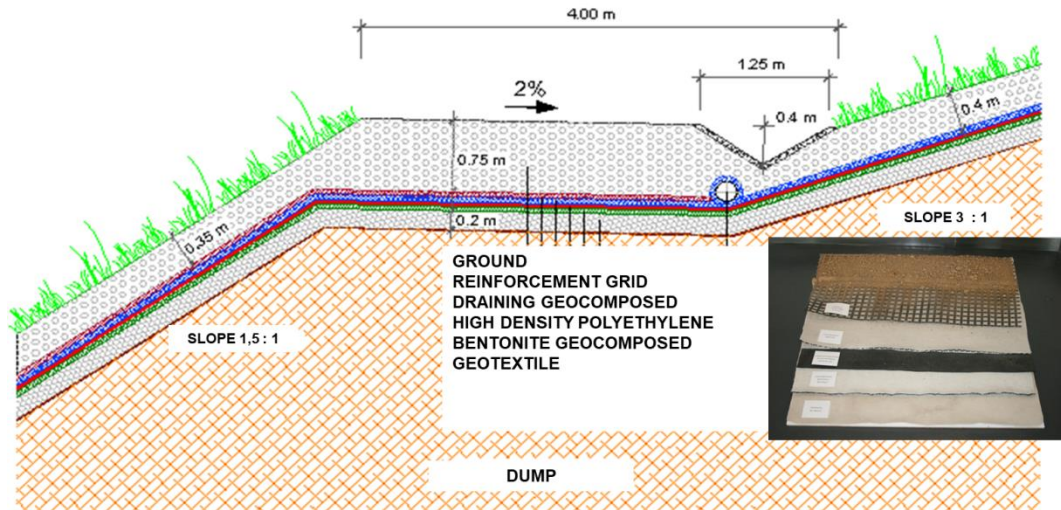
Functions:

- To prevent the entrance of water in the dump, avoiding the generation of leachate and the material dispersion.
- Insulation, avoiding mercury evaporation in the dump surface



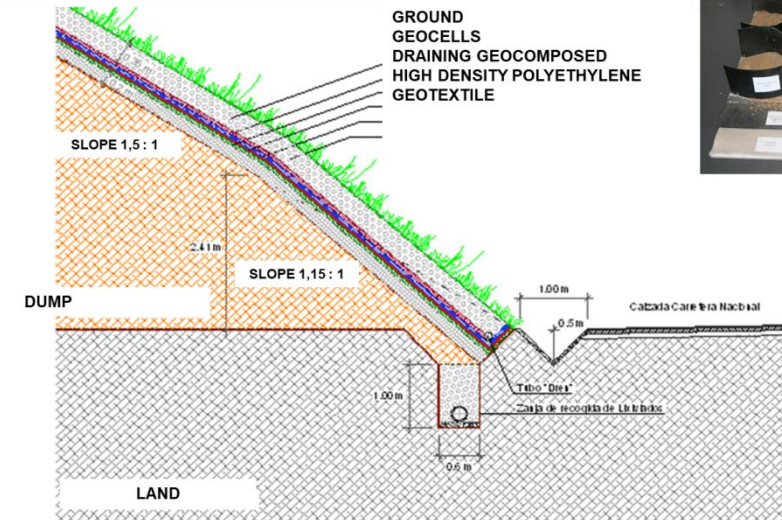
Reconditioning of the “Cerro de San Teodoro” dump

PHASES



SEALING SURFACE SCHEME
LOW INCLINATION SLOPE

ESQUEMA DEL TALUD / CUMBRERA DE LA ESCOMBRERA



SEALING SURFACE SCHEME
HIGH INCLINATION SLOPE

ESQUEMA DEL TALUD / PIE DE LA ESCOMBRERA

PHASES



3.INSTALLATION OF A COLLECTION, CIRCULATION AND EVACUATION WATER SYSTEM

Aim: To avoid the erosive effects which can affect the dump stability

Reconditioning of the “Cerro de San Teodoro” dump

PHASES

ENVIRONMENTAL MONITORING

GIS AZOGUE

(GEOGRAPHIC INFORMATION SYSTEM ABOUT ALMADEN DUMP)

- System designed to store, manipulate, analyze, manage, and present the **environmental data** about the monitoring of Almaden dump.
- Incorporate **topography and orthophotos**, and **analytical controls** of the environmental characterization
- On a GIS web platform (so that information can be consulted on a private platform over the **Internet**).
- It is a **public information** for everybody

Enter:

<http://www.ctndm.es/proyectos/1-in.php>

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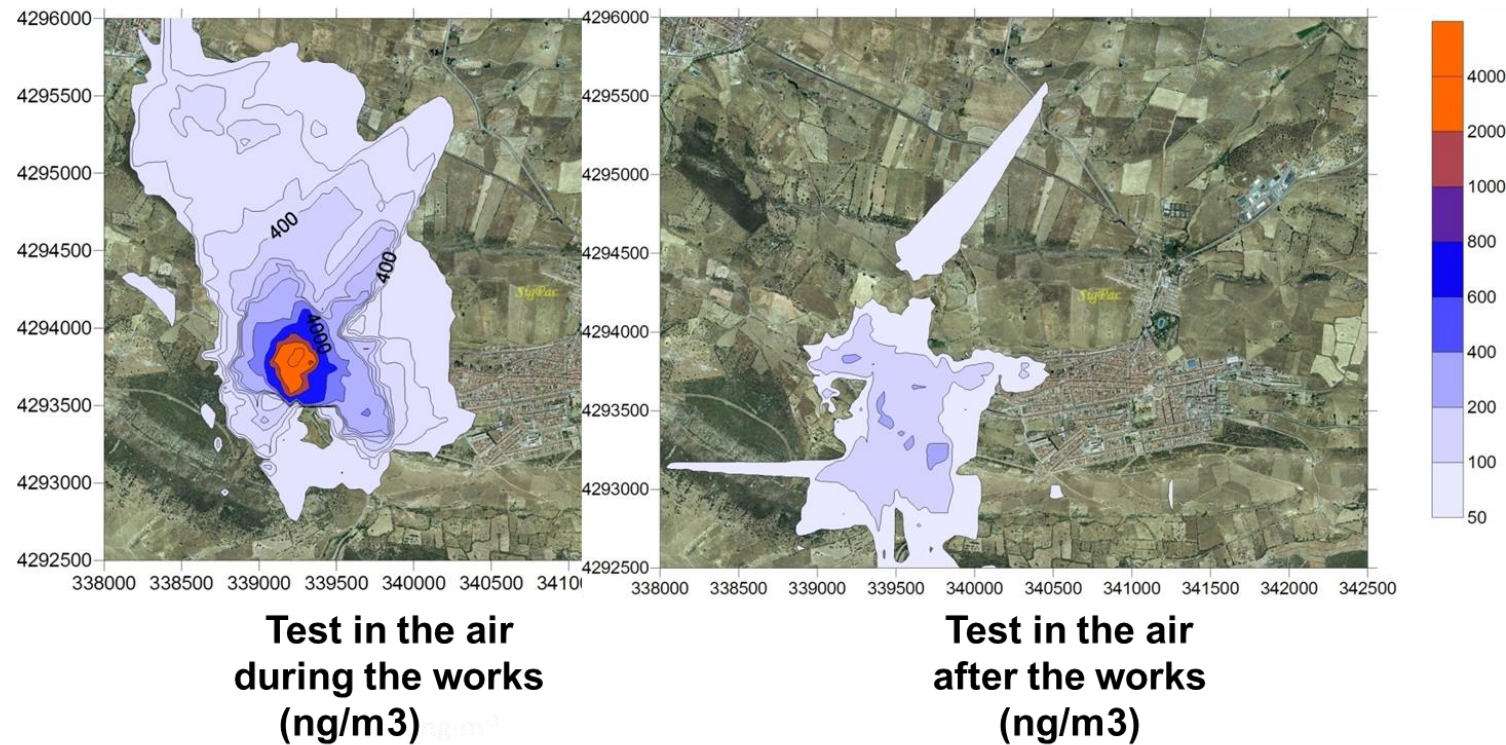
Reconditioning of the “Cerro de San Teodoro” dump

ENVIRONMENTAL MONITORING

RESTORATION OF THE WASTE HEAP IN THE SAN TEODORO ENCLOSURE

The first results:

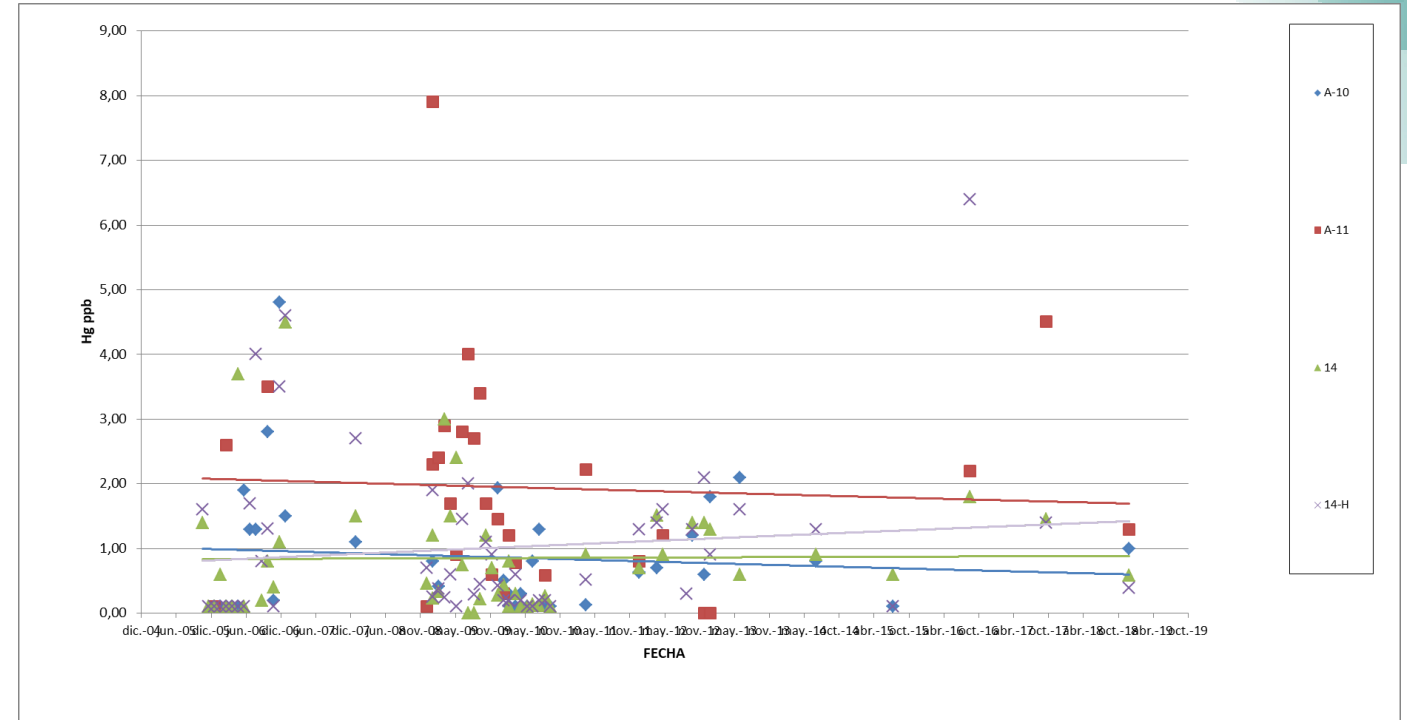
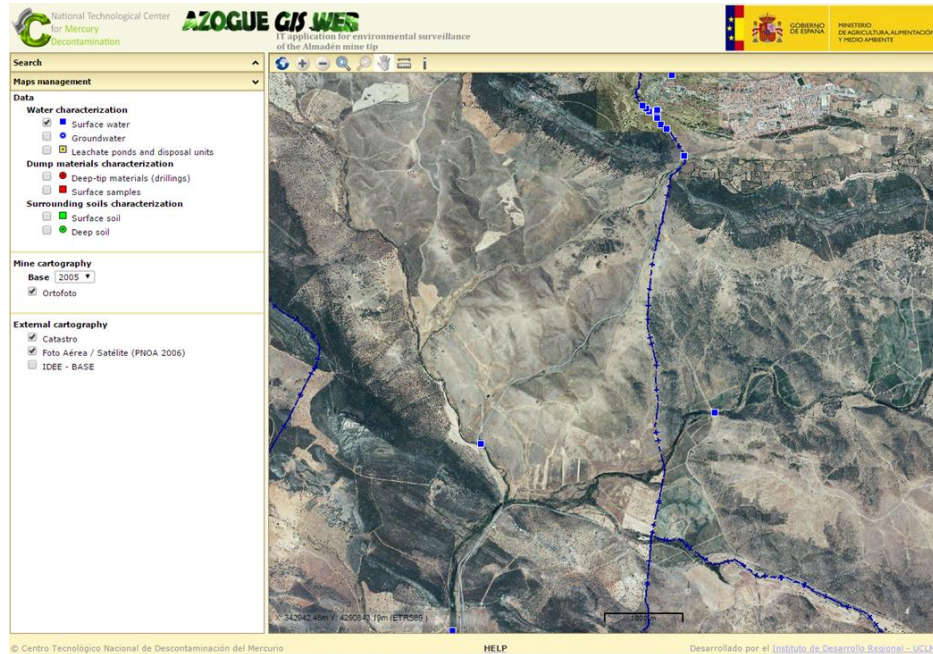
Emission to the atmosphere



Reconditioning of the “Cerro de San Teodoro” dump

ENVIRONMENTAL MONITORING

WATER MONITORING GROUNDWATER: WELLS AND SPRINGS



AZOGUE GIS WEB Geographic Information System which store the environmental information about the restoration project of the Almaden dump. More information in this web site. <http://www.ctndm.es/proyectos/1.php>

The restoration works are reducing:

- The material dispersion and mercury evaporation
- The lixivate production which had as final destination the surrounding streams
- The underground flow below the dump



ENVIROMENTAL MONITORING AREA

Since 1993, analytical measurements to determine the concentration of mercury in the Almadén area have been carried out.

This information lets us know the impact of the mercury in the soil and water (surface and groundwater) that surrounds our facilities.



LABORATORY AREA

The Centre has a laboratory area, which possesses a large amount of equipment to measure the amount of mercury in any kind of water/soil sample and a large (larch) range of measures.

The laboratory has equipment mainly for the determination of heavy metals.

Others parameters that we can measure are ions, cations, and methyl mercury

REMEDIATION PROJECT

“Reduce exposure of mercury to human health and the environment by promoting sound chemical management in Mongolia”



PROPOSAL : “Demonstration of new process of decontamination on mercury contaminated sites improving soil management and land use - MERCURY LIFE”

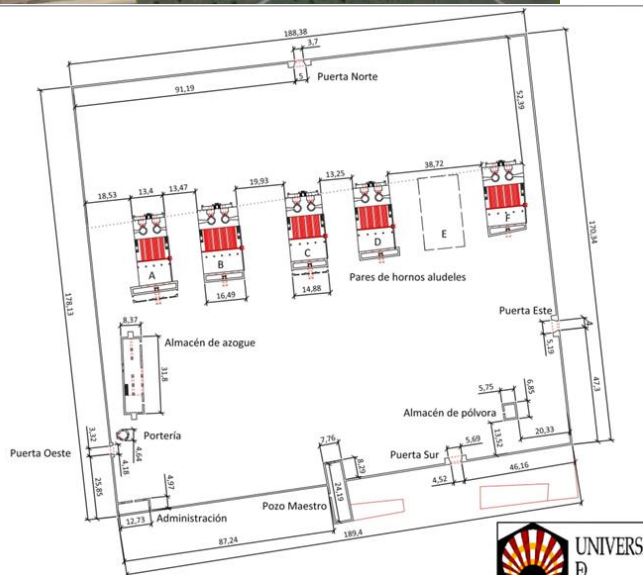
REMEDIATION OF MERCURY CONTAMINATED SITES. PRACTICAL CASES

DESCRIPTION

Almadenejos, is a small town of about 200 inhabitants, located about 12km southwest of Almadén. In north Almadenejos there is an old metallurgical treatment plant, “Cerro de Almadenejos” used for roasting Almadén’s and Almadenejos’s cinnabar and was in service between 1794 and 1861.

The project’s plot has a total area of 33,500m², with a northern slope of approximately 10%. The remains of mining industrial architecture and 5 old Hg extraction furnaces (“hornos de alaudeles”) still exist in different conservation states.

This site has been declared a Site of Cultural Interest: no environmental restoration or recovery of historical heritage work has been performed



CHARACTERIZATION

	Hg soils($\mu\text{g g}^{-1}$)	Hg air(ng m^{-3})	Reference
Almadenejos Metallurgical precinct n=16			
Mean	4.220	137	
Maximum	15.900	972	
Minimum	25	7	
Standard deviation	4.926	230	
Surrounding areas (SA) n=35			
Mean	43	21	
Maximum	174	80	
Minimum	4	2	
Standard deviation	40	21	
Total (MP and SA)	1.296 (4–15.900)	58 (2–972)	
Baselines			
Almadén baseline data	20–22		Molina et al. (2006)
Uncontaminated soil	0.01–0.03		Senesi et al. (1999)
Mediterranean basin		2–3	Wängberg et al. (2001)

Mercury content in CDA soils. (Martínez-Coronado et al., 2010)

Almadenejos Metallurgical precinct n=23	Hg soils($\mu\text{g g}^{-1}$)	Hg air(ng m^{-3})
Mean	1.782,41	53,83
Maximum	2.499	138,87
Minimum	40	1,87

Mercury content in CDA soils. (Centro Tecnológico del Mercurio, February 2019)

There is no several studies of Hg measurements in soils and atmosphere, providing data on high Hg levels that affect land use. systematic environmental characterisation of the site, but there have been

The studies conclude that the Cerco de Almadenejos is contaminated with Hg concentrations in soil and air ranging between high and very high. It constitutes a source of emission of gaseous Hg, contaminating the vegetation and the air beyond the metallurgical site, being a potential danger to health and environment.

TREATMENT ALTERNATIVES STUDY

From Mercury Technological Center has been studied the best available techniques (BAT) for mercury polluted sites in generals and a solution for the site.

Techniques have been analyzed with the following criteria:

- ✓ Advantages/Disadvantages of the technique.
- ✓ Effectiveness of pollutant recovery (Hg mainly) and/or environmental risk control.
- ✓ Estimated cost-benefit. Unitary price €/m³ or
- ✓ Difficulty/simplicity of implementing.
- ✓ Warranties, in terms of goal achievements and durability.
- ✓ Environmental and social impact.



- ✓ Conventional chemical soil stabilization.
- ✓ Immobilization of heavy metals using Reactive Zerovalent Iron Nanoparticles (RNIP).
- ✓ Phytoremediation (Hg and As plant absorption).
- ✓ Soil washing (as a pretreatment to concentrate pollutant in the fine fraction).
- ✓ Thermal desorption of volatile heavy metals (such as Hg and Cd).
- ✓ Encapsulation.

PREVIOUS EXPERIENCIES

MAYASA developed the project “Reducing mercury exposure to human health and the environment by promoting the sound management of chemicals in Boroo” which had 3 t of metallic Hg spill.

The main project objective was to demonstrate the available techniques for treating mercury-contaminated soils.

Several laboratory tests were performed in order to demonstrate effectiveness of some remediation technologies, to remediate the contaminated site, and to define and redesign the demonstrative field pilot tests at the Boroo site like **Chemical stabilisation using using LG-MgO as a stabilising reagent.**



Previous studies, international experience, and the special characteristics of the site, led to the study of LG-MgO behaviour in the Cerco de Almadenejos soil samples by conducting laboratory tests that, using different reagent doses and different maturation time, have achieved up to 87% reduction in Hg concentration.

PREVIOUS EXPERIENCIES

Results chemical stabilization pilots tests (UNIDO project)

Comp.	Units	S1		S2		S3		S4	
		BT	AT	BT	AT	BT	AT	BT	AT
Dry matter	%	95.30	83.80	96.60	85.60	95.10	84.70	96.20	83.80
Arsenic (As)	mg/kg d.m.	835	-	1,020	-	772	-	1,480	-
Cadmium (Cd)	mg/kg d.m.	3.56	-	4.25	-	3.62	-	8.93	-
Mercury (Hg)	mg/kg d.m.	14.20	-	16.20	-	16.10	-	20.40	-
Leachable Arsenic (As), TCLP	mg/kg d.m.	6.67	0.02	18.40	<0.05	6.27	<0.05	16.90	<0.05
Leachable Cadmium (Cd), TCLP	mg/kg d.m.	0.095	<0.01	0.264	<0.01	0.091	<0.01	0.250	<0.01
Leachable Mercury (Hg), TCLP	mg/kg d.m.	0.020	0.007	0.206	0.019	0.023	<0.005	0.251	<0.005

BT: before treatment

AT: after treatment

*d.m. dry material

Results chemical stabilization laboratory tests (reagent doses 10 % - 20%). Mercury Technological Center. April 2020.

Ref. sample	Maduration time (h)	(*) Hg mg/kg B.T.	(*) Hg mg/kg A.T.
H-1	4	1.56	0.33
	6		0.30
	12		0.28
	24		0.27
S.3.3	24	22.9	4.03
	48		3.03
	72		2.50

BT: before treatment

AT: after treatment

Based on; previous studies, laboratory tests and the Boroo project, and take into account the situation of the site, an area with low possibilities to apply conventional treatments due to geographic (transport difficulties to supply product), economic (treatment cost), and /or legal limitations.

MAYASA proposes to carry out the environmental remediation of the mercury-contaminated site, using chemical stabilisation technology in situ with the LG-MgO stabilizer.

The project remediation will enable future enhancement of an industrial historical heritage, as yet unavailable due to the environmental conditions of its surroundings, which would also enhance the area’s industrial tourism (rural environment in which this activity is being promoted as an option for the future).



THANK YOU FOR YOUR ATTENTION

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