December 2001 ECN-C--01-069

ENVIRONMENTAL CRITERIA FOR CEMENT BASED PRODUCTS

ECRICEM

Phase I: Ordinary Portland Cement

H.A. van der Sloot*
D. Hoede*
R.P.J.J. Rietra*
R. Stenger**
Th. Lang**
M. Schneider***
G. Spanka***
E. Stoltenberg-Hansson****
A. Lerat*****

* ECN, Petten, The Netherlands
** Holcim Group Support Ltd, Holderbank, Switzerland
*** VDZ, Düsseldorf, Germany
****NORCEM, Brevik, Norway
*****Ciments d'Obourg, Obourg, Belgium

Revisions		
A		
B		
Made by: H.A. van der Sloot	Approved: R.N.J. Comans	ECN-Clean Fossil Fuels Emission characterisation & reduction
Checked by: A. van Zomeren	Issued: C.A.M. van der Klein	

Acknowledgement/Preface

This work was carried out with financial support from Holcim/Ciments d'Obourg, Norcem and VDZ.

Abstract

Regulations such as the European Construction Products Directive (CPD) or national Drinking Water Standards contain provisions to exclude or minimise adverse effects on environment or public hygiene through the use of construction materials.

The assessment of the "environmental quality" of construction products such as cement and cementitious products is usually based on the determination of their leaching characteristics, e.g. the potential release of constituents such as trace elements (heavy metals) or organic compounds to the environment when the products get in direct contact with water or soil.

The report on hand presents the results of the first part of a more comprehensive study with the following main objectives:

- ➢ To support and facilitate the environmentally sound use of alternative fuels and raw materials (derived from various waste streams) in cement and concrete production.
- ➢ To support the reuse/recycling of construction debris (demolished concrete) in construction projects, e.g. as aggregates in new concrete, as fill materials in road construction, or others.
- ➢ To develop and propose environmental quality criteria and control procedures for cements and cement based products.

The study was carried out by a project team consisting of scientific research institutions (Energy research Centre for the Netherlands - ECN, Forschungsinstitut der Zementindustrie Germany - VDZ) and members of the cement industry (Holcim Group Support Ltd., Ciments d'Obourg, Norcem A.S.).

Part I of the project is focussing on the leaching behaviour of Ordinary Portland cements (OPC). Ten commercial cements were selected covering a wide range of trace element compositions, and two cements with artificially increased trace element contents were produced in a specific pilot installation in addition.

After detailed chemical and physical characterisation of the test cements, a series of different leaching tests was applied on standard mortar samples in order to systematically characterise their leaching behaviour. Geochemical modelling supported the development of model predictions of the long term release of trace elements under various exposure scenarios.

Selected major conclusions of the study so far are:

- ➢ The pH dependence test is the test procedure best suited to characterise the generic leaching behaviour of trace elements in cement based products, and thus should form the basis for release assessments under different exposure scenarios.

- ➢ There are significant differences in the generic leaching characteristics of various groups of trace elements (e.g. "regular" metals, "oxyanions", and metals forming soluble salts).
- ➢ In general, there is no systematic correlation between the total contents of trace elements in cement and cement mortars, and the leaching rates.
- ➢ For some elements such as chromium, arsenic or antimony occurring as "oxyanions", elevated concentrations in cements may lead to increased leaching rates under specific test conditions.
- ➢ However, zinc contents of up to 0.2 % in cement are not expected to have a detrimental effect even under worst case scenarios.
- ➢ Chromium and aluminium require more systematic investigations due to their specific behaviour and response to changing pH conditions under different exposure scenarios.
- ➢ In certain life cycle stages of concrete (recycling or disposal), carbonation of small particle size fractions may play an important role in the release of trace elements.
- ➢ Test procedures have to be carefully adapted to the application and exposure scenarios under consideration. Slightly modified "compliance tests" are proposed to allow predicitions of the long term leaching behaviour of trace elements in different applications.

Part II of the project will mainly focus on composite cements (with blast furnace slag, fly ash or natural pozzolans) and construction debris. Using available test data model predictions of trace element release based on test results for different exposure and utilisation scenarios will be verified in selected field applications. Selected ecotoxicological tests on mortar leachates will complement the work program.

Key words: Leaching, long term behaviour, mortar, Portland cement, environmental impact, trace elements, life cycle.

CONTENTS

1. INTRODUCTION

1.1 Background

The protection of the immediate environment of structural works is one of the essential requirements of the European **C**onstruction **P**roducts **D**irective (CPD). According to the CPD, construction products can only be put on the market, if the structural works built with them fulfil the relevant requirements for hygiene, and the protection of health and the environment. These essential requirements in the respective standards are for now specified at the national level by the individual member states until the next revision of the standards. At that time, harmonised European specifications shall be available.

Cement and cementitious materials are considered to fulfil the fundamental requirements of the European Construction Products Directive and the corresponding national regulations. Therefore a technical regulation like the cement standard EN 197 in general does not cover separate requirements for determining compliance of cementitious materials with criteria on hygiene, health and environmental protection. Further regulations are laid down in cases where it appears necessary for constructive applications requiring a particular protection of water, soil and air.

In this context the assessment of the environmental quality of cement and cementitious products is usually based on leaching characteristics, i.e. the release of constituents such as trace elements or organic compounds when the materials are in contact with groundwater or soil. However, the relation between release of substances like trace elements or organic components under specific laboratory test conditions and actual field situations may lead to some contradictions. Therefore, environmental testing has to be optimised such that a manageable and effective system of quality control can be designed. The findings of the project will be useful for the standardisation work taking place in CEN, for example in TC 51 ‘Cement’, TC 104 ‘Concrete’ and TC 164 ‘Water supply’.

Emphasis is mainly given to the following items:

- ❑ exposure of concrete structures in direct contact with groundwater, surface water or soil **(„primary“ applications or „service life“),**
- ❑ exposure of mortar or concrete to drinking water in distribution systems **(„primary“ application),**
- ❑ reuse of demolished and recycled concrete debris as aggregates in new concrete, in road construction, dam fill etc. **(„secondary“ applications),**
- ❑ landfilling of demolished concrete **(„end-of-life“ application).**

The trace element contents of commercial cements may vary broadly as a consequence of the use of various natural fuels and raw materials. Increasing concern has been raised with the use of ‘alternative’ (= waste derived) fuels and raw materials which may both increase or decrease the trace element content in cement [1,2,3].

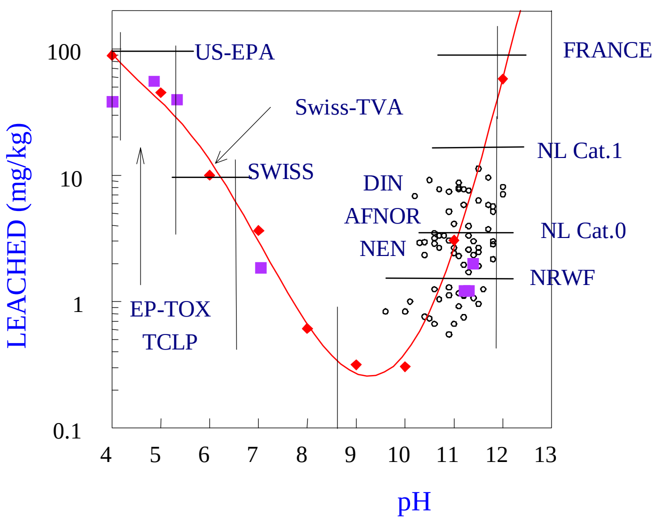
Many studies have been carried out on the leaching behaviour of cementitious products [4,5,6,7,8,9,10]. However, the findings of several studies [11,12,13] have demonstrated that the chemical composition (i.e. the trace element content) of cement has no direct relation to the leaching characteristics and, thus, is not a good indicator for the environmental quality of cement based products.

These studies have also shown that the release of constituents (trace elements) from cement based products in contact with water during service life is mainly diffusion-controlled and affected by various physical and chemical retention mechanisms [6,7,13]. The knowledge of these mechanisms, i.e.

- ❑ the physical retention of the potentially leachable fraction,
- ❑ the chemical retention of elements fixed in the hardened cement paste matrix, and
- ❑ the changes in conditions controlling trace element release such as the decrease of the pH value due to carbonation

holds the key in defining environmentally sound trace element levels in clinker and cement.

A variety of laboratory leaching tests has been developed worldwide, of which a few are already used for regulatory control purposes. This is a major cause for confusion as the basis of reference is not the same, and different tests may lead to different results and different interpretations. As an example Figure 1.1 shows the leachability of lead from **M**unicipal **S**olid **W**aste **I**ncinerator (MSWI) bottom ash as a function of the pH value in relation to various regulatory limits and standard tests.



Horizontal lines:	*Limit values in various regulations.*
Vertical lines:	*pH values applied in corresponding standard tests.*
Standard Tests:	
US-EPA:	*EP-TOX (predecessor of TCLP)*
Switzerland:	*TVA – Swiss CO2 test*
Germany:	*DIN – German batch leach test (S4)*
Netherlands:	*NEN – Dutch column leaching test*
France:	*AFNOR - French batch leaching test*

Figure 1.1 *Leachability of lead from MSWI bottom ash as a function of the pH value in relation to various regulatory limits and standard tests. [46]*

In order to describe the release of trace elements from cementitious materials, so-called ‘compliance tests’ are available. Their results are available after a comparatively short time of testing. However, for a sound understanding of the short and long term leaching behaviour of construction materials, these single ‘compliance’ leaching tests generally are of limited use. Therefore, ‘characterisation’ tests focussing on the basic characteristics with regard to the long term leaching behaviour are needed. In addition, parameters influencing the principal leaching mechanisms have to be determined. The information generated can then be used for the evaluation of different exposure scenarios.

1.2 Project Organisation and Objectives

ECRICEM (‘**E**nvironmental **Cri**teria for **Cem**ent Based Products’) Phase I is the first part of a more comprehensive project set up by a consortium consisting of the following partners:

- ❑ Energy research Centre for the Netherlands (ECN)
- ❑ Holcim Group Support Ltd. (Holcim) and Ciments d’Obourg (COB)
- ❑ Verein Deutscher Zementwerke (VDZ)
- ❑ Norcem A.S.

The following **main objectives** of the entire ECRICEM project have been identified by the partners:

- ❑ To support and facilitate the environmentally sound use of alternative fuels and raw materials (derived from various waste streams) in cement and concrete production.
- ❑ To support the reuse/recycling of construction debris (demolished concrete) in construction projects, i.e. as aggregates in new concrete, as fill materials in road construction, etc.
- ❑ To develop and propose environmental quality criteria and control procedures for cements and cement based products to both producers and regulators of construction materials.

The main **achievements** for environment and society resulting from these objectives would be:

- the conservation of natural (fossil) resources
- the reduction of waste streams requiring separate waste disposal options such as landfilling or special incineration
- the development and support of a superior eco-efficient recovery/reutilisation scheme for waste streams with minimum environmental and social impact
- the reduction of greenhouse gas generation through substitution of fossil resources by selected and carefully controlled waste categories.

In addition comes the economical benefit to the cement industry through maintaining its competitiveness due to cost reduction in the manufacturing process.

The following **targets** have been defined for project phase I:

- ❑ Establishment of an inventory of contents and leachability of trace elements in Portland cements produced with different natural fuels and raw materials at various locations world-wide.
- ❑ Investigation of the influence of alternative fuels and raw materials on content and leachability of trace elements in Portland cements.
- ❑ Increase of the fundamental knowledge about the incorporation of trace elements in clinker phases and about the leaching mechanisms prevalent in cement based products.
- ❑ Development of the work programme for ECRICEM phase II.

2. EXPERIMENTAL

According to the work programme of ECRICEM phase I, the experimental section consisted of the following individual tasks:

- Collection of commercial cements
- Preparation of special clinkers with increased levels of heavy metals
- Determination of the chemical composition of the selected test cements
- Determination of the physical properties of the selected test cements
- Preparation of mortar samples for further testing
- Physical characterisation of the mortar samples
- Environmental characterisation (leaching tests)
- Geochemical modelling
- Interlaboratory comparison

2.1 Cement Samples

Seventeen commercial cements in total were collected from various sources world-wide. Out of these seventeen commercial cements, ten samples were selected for further testing based on their detailed chemical composition, i.e. trace element contents. In addition, two cements (W1 and W2) were produced in a special test facility using an industrial raw meal spiked with trace elements (see Chapter 2.1.2). Test cement designation is given in Table 2.1.

Table 2.1 *Designation of Test Cements*

Sample Designation	Cement Type	Cement Constituents	Clinker produced with Alternative Fuels
Commercial Cements			
H1	CEM I	Clinker, gypsum, filler	Yes
N1	CEM I	Clinker, gypsum	Yes
H3	CEM I	Clinker, gypsum, filler	No
H5	CEM II-L	Clinker, gypsum, lime-stone (14 %)	No
H6	CEM I	Clinker, gypsum	Yes
D1	CEM I	Clinker, gypsum, filler	Yes
H7	CEM I	Clinker, gypsum, filler	No
N2	CEM I	Clinker, gypsum, filler	No
D2	CEM I	Clinker, gypsum, filler	Yes
H9	CEM I-HS	Clinker, gypsum	Yes
Special Cements			
W1	CEM I	Clinker, gypsum	No
W2	CEM I	Clinker, gypsum	No

2.1.1 Commercial Cements

Nine commercial Portland cements (type CEM I, according to the European cement standard EN 197 [15]) and one blended cement with a limestone filler (type CEM II-L) were selected for further testing (see Table 2.1). One of the selected Portland cements was a sulfate resistant cement type CEM I-HS, i.e. with low aluminium (C_3A) content.

Out of the ten commercial cements, six were manufactured using alternative (waste) fuels such as tires, waste oil, impregnated saw dust, paper sludge, or solvents – up to a thermal substitution rate of 42 % at maximum. Four commercial cements were manufactured by using conventional fuels only (i.e. coal, oil).

2.1.2 Special Cements

In order to evaluate the leaching characteristics of cements with trace element contents higher than the common range of commercial cements, two 'artificial' clinkers were produced in a small gas-fired rotary kiln at a specific test facility. A short description of the test facility (with a capacity of 150 kg clinker per day) is given in Annex 1 together with the test parameters applied during the production of the spiked clinker.

The spiked clinkers were produced by artificially introducing elevated contents of trace elements ('spikes') to an industrial cement raw meal. The clinkers were prepared such as to arrive at approximately 2 times and 10 times the levels in clinker as specified in the Swiss Guidelines on the Use of Waste Materials in the Cement Industry (BUWAL Values [24], see Table 2.2).

Table 2.2 *BUWAL Values of Trace Elements in Clinker (according to the Swiss Guidelines on the Use of Waste in the Cement Industry, 1998), and Target Values of Spiked Clinkers(in mg/kg)*

	BUWAL Values		**Target Values**	
Trace Element	**Clinker**	**Portland Cement**	**Clinker for Cement W1**	**Clinker for Cement W2**
As	40	--	80	400
Sb	5	--	10	50
Be	5	--		
Pb	100	--	200	1000
Cd	1.5	1.5	3	15
Cr	150	--	300	1500
Co	50	--		
Cu	100	--		
Mo	--	--	80	400
Ni	100	--		
Hg	--	0.5		
Se	5	--		
Tl	2	2		
Zn	500	--	700	3500
Sn	25	--		

Two raw meal batches of 560 kg each were mixed with the metal 'spikes' at calculated proportions, and granulated to form pellets of 3 – 8 mm size. The pellets were fed to the test kiln at a rate of 30 – 35 kg per hour with a maximum burning temperature of 1450°C on average. For more technical details see Annex 1.

The two clinkers produced were ground in a laboratory mill and mixed with gypsum ('hemihydrate', $CaSO_4$ x 0.5 H_2O) to produce an ordinary Portland cement type CEM I at an SO_3 level of approximately 3 %. For comparative testing, a laboratory cement (designation 'D2', see Table 2.1) was prepared with industrial clinker produced from the same (non-spiked) raw meal in a full-scale commercial cement plant.

2.1.3 Chemical Composition

Major Oxides
In the test cements, major oxides were determined by means of X-ray fluorescence spectrometry (XRF) applying fused bead preparation technique. Alkalis were measured by means of atomic absorption spectrometry (AAS). Total sulfur – expressed as SO_3 – was determined using a sulfur analyzer with selective infrared detection.

Chlorides were analyzed by means of potentiometric titration after sample pretreatment with nitric acid. Free lime was determined complexometrically using an ethylene glycol extraction procedure.

Trace Elements
Determination of trace elements was carried out in duplicate by means of ICP-MS (inductively coupled plasma mass spectrometry), after microwave digestion using a mix of nitric and fluoric acid. In some cases, the results obtained were cross-checked by means of AAS techniques.
Hexavalent (water - soluble) chromium was determined by means of ICP-AES (inductively coupled plasma atomic emission spectrometry) after extraction with demineralised water at a water-cement ratio of 5 to 1 for about 30 minutes.

2.1.4 Particle Size Distribution

The particle size distribution of the test cements was determined with a laser granulometer type CILAS 715.

2.2 Mortar Samples

2.2.1 Preparation and Physical Tests

Mortar samples were prepared from the test cements in accordance with the European standard EN 196-1 ('Methods of Testing Cement – Determination of Strength'[16]). After demoulding at the age of 24 hours, the mortar samples for the leaching tests were cured at 20 ºC for another 27 days in plastic bags to prevent pre-leaching. Test samples were dispatched to the partners after 10 days of curing.

Characteristic physical properties of the standard cement and mortar samples – i.e. setting time, water demand, soundness, and compressive strength at 1, 2, 7 and 28 days – were determined according to the European cement standard EN 196-1 and 196-3, respectively (see Table 2.3). In addition, microscopic investigations (porosity, microstructure) were carried out.

Table 2.3 *Physical and Structural Tests*

Test	**Method**
Compressive strength (1,2,7,28 d)	EN 196-1
Setting time	EN 196-3
Soundness	EN 196-3
Porosity	Optical microscopy (thin sections)
Structure/morphology	Scanning electron microscopy

2.2.2 Structural Investigations

Structural investigations were carried out on standard mortar samples made with the test cements by means of optical microscopy and scanning electron microscopy (SEM). Structural properties such as air void content and capillary porosity may have an influence on physical properties (compressive strength) and on leaching characteristics.

Optical Microscopy

Microscopical investigations were carried out on thin sections in transmitted light. Capillary porosity is measured with a spotlight meter on samples impregnated with a fluorescent resin. The intensity of the fluorescence light is proportional to the water to cement ratio. A standard concrete serves as reference sample for the assessment.

The contents of cement paste, aggregates and air voids were determined by means of point counting (2000 points in total).

For more details, see Annex 2.

Scanning Electron Microscopy

Microstructural investigations were carried out by means of SEM equipped with a backscatter detector on polished mortar samples coated with a thin layer of gold. Only two samples (H1 and N1) were investigated, because little additional information was obtained to that of optical microscopy.

2.3 Leaching Tests

2.3.1 Test Procedures

A series of leaching tests [17,18,19,20,21] was carried out on the standard mortar samples addressing various aspects of leaching. The test conditions are described in Table 2.4 and in Annex 3. In addition pore water was obtained by pressing water out of hardened mortar bars with a special equipment and a powerful press (see Annex 3).

Except for the leaching tests on monolithic samples, the mortars were crushed to different particles sizes according to the standards specified in table 2.4 respectively of 95 % < 4 mm (pH dependence leaching test, EN 12457-3 and concise test). For the availability tests (NEN 7341), the material was further ground to a particle size of 95 % < 125 µm.

Test name:	**NEN 7341** Availability test	**PrEN xxx** pH dependence test	**NEN 7345** Diffusion Test	**NEN 7345** Diffusion Test	**PrEN xxx** Compliance test for monolithic material	**EN 12457-3** Compliance test for granular materials	**Concise test**	**EN 12457-4** Compliance test for granular materials
Type of test:	Batch extraction	Batch tests at specified conditions	Tank leaching test	Tank leaching test modified pH	Tank leaching test	Batch test	Batch test with two L/S values and two controlled pH conditions	
Country:	Netherlands	CEN TC 292 WG6	Netherlands	Netherlands	EU CEN TC292	EU CEN TC292	WASCON 1997	EU CEN TC292
Particle size:	95%< 125 µm	< 2 mm	> 40 mm	> 40 mm	> 40 mm	< 4 mm (95%)	< 2 mm	< 10 mm (95%)
Leachant:	DMW at fixed pH=7 and pH=4, using HNO_3	DMW with pH control using HNO3 or NaOH (pH 3-12)	DMW initially acidified to pH=4 with HNO_3	DMW flushed with air or air with increased CO_2 to maintain pH = 7.5 – 8 in eluate	DMW	DMW	DMW without and with pH control using HNO3 or NaOH (pH 4 –7)	DMW
Amount of solid:	16 g	100 g	> 100 g	> 100 g	> 100 g	100 ± 5 g	100 g	100 ± 5 g
L/S (l/kg) per step:	50	10	L/V = 5 l/l	L/V = 5 l/l	L/V = 1.5 l/l	2 in 1st step 8 in 2nd step	2 and 10	10
Maximum accumulated:	100	10	Not applicable	Not applicable	Not applicable	10	10	10
Number of steps:	2	8	8	8	3	2	4	1
Contact time per step:	3 hours	48 hours	Varies (64 days for all 8 steps)	Varies (64 days for all 8 steps)	Varies (2 h up to 48 h)	6 h for 1st step and 18 h for 2nd step	48 hours	24 hours
Renewal of leachant or solid:	New leachant	not applicable	New leachant	New leachant	New leachant	New leachant	not applicable	
Method of agitation:	magnetic stirrer	ANC mode: End over end rotation, 5 - 10 rpm. pH stat mode: magnetic stirrer	No agitation	No agitation	Mild stirring	End over end or roller-table rotation (10 rpm)	ANC mode: End over end rotation, 5 - 10 rpm pH stat mode: magnetic stirrer	End over end or roller-table rotation (10 rpm)
Filtration/filter size:	0.45 µm	0.45 µm	0.45 µm	0.45 µm	0.45 µm	0.45 µm	0.45 µm	0.45 µm
Comments:		WG document			Some details not yet fixed		[19]; Own pH same as EN 12457-3	Same as DEV-S4

Table 2.4 *Leaching Test Conditions*

2.3.2 Analytical Methods

The following methods were applied in the analysis of the leachates:

Component	Analytical Method
Metals/ Non-metals	ICP-AES, ICP-MS, AAS
Anions (halogens, sulfate)	Ion chromatography

2.4 Geochemical Modelling

The geochemical codes MINTEQA2 and ECOSAT [22,23] were applied for the modelling of the chemical speciation in leachates from crushed mortar samples. Data taken from the pH-dependence experiments were used as input for the models. Davies equation was applied to correct for ionic strength effects. The saturation indices for the different chemical phases were calculated under the same conditions as measured in the leachates.

No parameters were available to describe ettringite – element substitutions which is particularly relevant for so-called 'oxyanionic' species, i.e. Mo, V, or As.

2.5 Modelling of Long-Term Release

Based on previous experience made in modelling release of constituents from monolithic specimen [6,8,11,13,28], estimates were made on the long-term release regarding three different exposure scenarios in the application of cement based products, such as:

- concrete pilings in aggressive soil environment
- concrete pillars in flowing water (river)
- concrete structures exposed to weather conditions

In addition, the potential release of constituents from construction debris with a typical particle size was modelled to evaluate the contribution of the different size fractions in the leaching process.

2.6 Data Presentation and Interpretation

Leaching test results may be expressed either as

- Leachate concentration in [mg/l]
- Constituent release in [mg/kg of material] for granular materials or
- Constituent release in mg/m^2 for monolithic materials.

Leach test results are frequently expressed as eluate concentration, as this is the form in which results become available after eluate analysis. Subsequent data conversion may be necessary for different purposes. The eluate concentration as measured is used for geochemical modelling. Some regulations use concentrations expressed in mg/l. Others use leached quantities (mg/kg dry matter) or other derived units, such as mg/m^2.
Conversion of measured leachate concentrations into constituent release is necessary for the comparison of data obtained in different leaching tests at different liquid to solid (L/S) ratios.

Conversion formula:
Constituent release [mg/kg] = leachate concentration [mg/l] x L/S ratio [l/kg]

However, in comparing results from different leaching tests it is important to take other aspects that control release of constituents into account (e. g. pH value, L/S ratio)

Presentation of data as measured eluate concentrations or as constituent release also can be necessary for the determination of the general leaching mechanism (see Figure 2.1). Examples:

- Chlorine (Cl) represents an availability controlled element. Data from tests at different L/S ratios expressed in [mg/l] lead to apparent differences, while data presented in [mg/kg] show that in all cases the whole fraction available for leaching is released.

- Silicon (Si) represents a solubility controlled element. Here, presentation of leaching data in [mg/kg] leads to differences, whereas data presented in [mg/l] show the solubility control in the pH region of 3 to 8 (constant concentration irrespective of L/S).

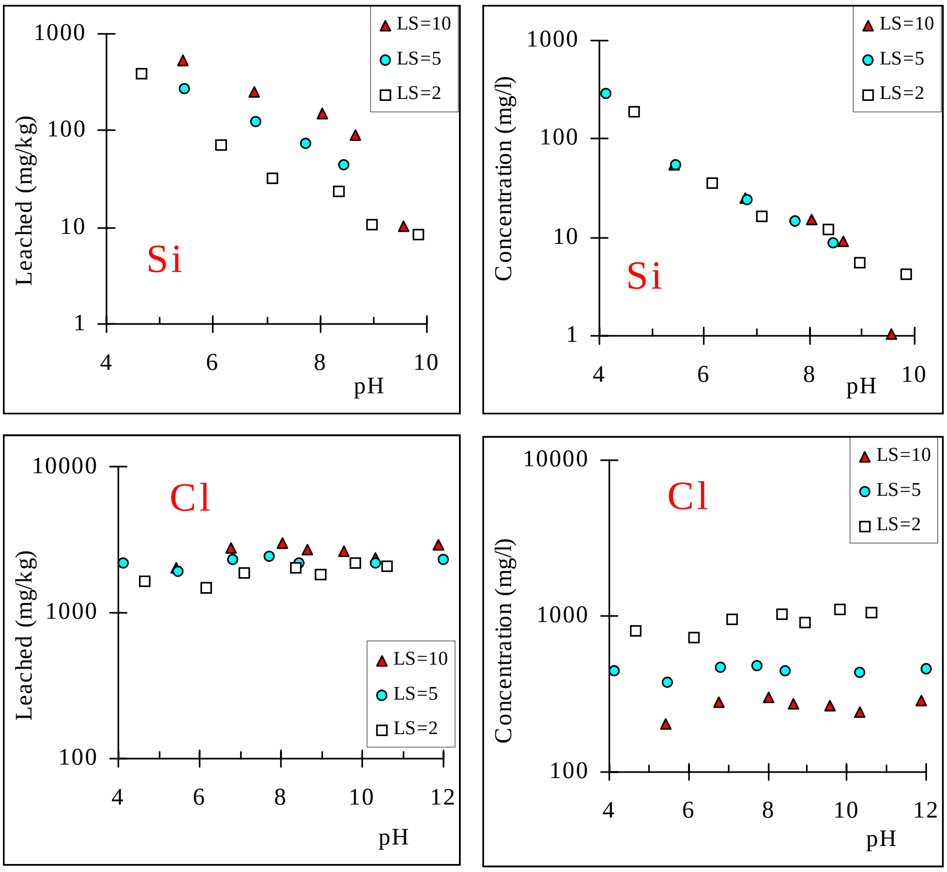


Figure 2.1 *Distinction between Solubility Control (Si) and Availability Control (Cl) in the Presentation of Leaching Test Results*

2.7 Interlaboratory Test

To ensure a good comparison of analytical results among the project partners, two interlaboratory tests were carried out, i.e.:

- Direct analysis of a standard leachate
- Monolith leaching test and subsequent leachate analysis.

Standard Leachate Analysis
A standard eluate was prepared by leaching a mixture of coal fly ash and MSWI ash (at a ratio of 95 to 5) at a L/S ratio of 10. In this eluate, all relevant constituents were available in measurable concentrations. After a stability check, the eluate was distributed to all partners for analysis.

This test was designed to identify potential discrepancies in the analytical performance among the partners.

Monolith Leaching Test
A monolithic sample was distributed to all partners to carry out a tank leach test according to NEN 7345 [18]. The sample had been tested before in the framework of a previous European intercomparison test [26]. The material had been aged for more than 5 years resulting in some differences in the leaching characteristics compared to previous results.

The test was designed to check the general test performance of all partners.

3. RESULTS

3.1 Physical Properties

The results of the physical tests on cements and mortar samples according to the European cement standard EN 196 [16] are given in Annex 4.

All cement samples are in compliance with the specifications given in the cement standard EN 197. Differences in compressive strength between the test cements are due to differences in granulometric and chemical characteristics and due to differences in the physical structure of the hydrated mortars (porosity, air voids etc.).

Soundness of test cement ‘W1’ is not in compliance with the requirements due to the high free lime content of the clinker under the specific conditions of the pilot test kiln. Nevertheless, the strength development of the cement is not significantly impaired.

3.2 Particle Size Distribution

The particle size distribution of the test cements as determined by laser granolumetry is compiled in Annex 5.

3.3 Chemical Composition

The chemical composition of all test cements is given in Annex 6 both for major and minor oxides and trace elements. In Table 3.1, the range of the trace element contents of the commercial cements are compared to the special (‘spiked’) cements W1 and W2.

Table 3.1 *Trace element contents of the test cements (in mg/kg)*

	Commercial cements		Special cements	
	Range		W 1	W 2
Element	Min	Max		
As*	2	23	102	340
Be	0.5	3	0.8	0.9
Cd*	<0.1	1	0.3	1.2
Co	6	22	7	14
Cr tot.*	29	580	335	1400
Cr 6+	2	94	7	39
Cu	14	54	23	22
Hg	<0.02	0.1	0.03	0.08
Mo*	<1	8	46	202
Ni	14	75	14	42
Pb*	6	106	50	13
Sb*	<1	5	8	31
Sn	<1	14	< 1	3
V	22	230	25	27
Zn*	30	380	502	2030

**Spiked in the pilot cement kiln*

3.3.1 Commercial Cements

The individual data in Annex 6 show elevated contents of some metals such as zinc (H1, H9), chromium (H6, N1), lead (D1), and vanadium (H1, H5). The high chromium content in test cement H6 originates mainly from the natural raw materials, and not from the waste fuels used in the production of the clinker.

3.3.2 Special Cements

As, Cd, Cr, Mo, Pb, Sb and Zn were artificially ‘spiked’ to the raw meal of the clinker produced at the pilot test facility.

The analytical results (Table 3.1) demonstrate that As and Cr were nearly totally incorporated in the clinker, whereas only about 50 to 80 % of added Mo, Sb and Zn was retained in the clinker structure. Most of the Cd and Pb spiked to the raw meal was lost under the specific process conditions prevailing in the small test facility.

The behaviour of these elements in the test kiln is in contrast to their behaviour in a full scale commercial kiln. In a commercial kiln, these trace elements are almost completely (close to 100 %) bound to the solids produced – either clinker or kiln dust – due to the excellent retention capacity of a modern pre-heater kiln system [27].

Under the specific process conditions of the small test kiln – with limited contact of solids and gas due to the pelletised raw feed, the short residence time, and the lack of a preheater- a larger portion of the spiked elements – especially the ones with higher volatility (Cd and Pb)- left the kiln with the exhaust gases and were finally deposited on the filter system (textile filter and activated carbon filter).

3.4 Structural Properties of Mortar Samples

The results of the microscopical investigations on the mortar samples are compiled in Annex 2 together with the experimental details.

Thin section analysis demonstrates structural similarities, but also some differences in the test mortars, for example in homogeneity and porosity of the hardened cement paste, air void content and size, and development of microcracks.

The mortars produced from the different cements can be characterised as follows:

- H1 results in the densest, and H5 in the most porous hardened cement paste (capillary porosity),
- N1 and H6 result in the lowest contents of total air voids,
- H1 results in the highest content of total air voids and of small air voids < 0.25 mm,
- N2 results in the lowest content of small air voids < 0.25 mm,
- W1 results in the highest content of air voids > 0.25 mm,
- H6 results in a higher content of microcracks compared to the other samples.

The differences in air void structure and contents may influence the behaviour in the leaching tests. However, the air voids are in most samples evenly distributed – an indication of proper mortar compaction. The total content of air voids in the mortar samples ranges between 3.4 and 7.5 %. The content of small air voids < 0.25 mm is between 0.3 and 3.2 %.

3.5 Interlaboratory Test

To evaluate the analytical and laboratory performance, a standard eluate and a mortar sample were circulated between the partners.

Analysis of Standard Eluate
In Annex 12 the data obtained by the partners for a standard eluate are given. The results indicate that not for all elements a proper comparison is obtained. Differences in the determined eluate concentrations for single trace elements are high when the respective concentration in the eluate is very low, i. e. close to the detection limit. Detailed investigation of these differences will be part of ECRICEM phase II.

Tank Leach Test on Monolithic Samples
In Annex 13 the data obtained by all partners on the standard monolith leaching test according to NEN 7345 are collected. All data have been normalised to 32 days leaching for comparison. The results obtained by the different partners are in good agreement. They correspond to the results from the EU intercomparison on cement stabilised fly ash [26].

The results for the standard eluate analysis need further work, as some of the data show larger deviations than might be expected. The tank test data are more consistent and agree with the level of between laboratory variability that has been observed in EU wide intercomparison studies.

In ECRICEM II this intercomparison test between the partners shall be repeated.

3.6 Leaching Characteristics

In this section the different aspects of leaching of cement-based products are addressed. In Annex 7 to 10 all test data and extended graphical presentations are given.

3.6.1 pH Dependence Test

The pH dependence test provides a better means of evaluating cements than a tank leach test, which addresses just a very limited aspect of the entire leaching behaviour of cement-based materials. The pH dependence test data cover a much wider range of potential exposure conditions – service life (own pH and externally imposed pH), recycling stage as aggregate and end of life conditions after full carbonation.

In a previous project, the pH dependence leaching test (**A**cid **N**eutralisation **C**apacity ANC mode; the test is described in Annex 3) [21] was used to compare the leaching characteristics of various cement mortars [13,28,29]. The results derived from the pH dependence test for the cements studied in ECRICEM I are given as a generic behaviour in Figures 3.1 and 3.2.

In Annex 8 the complete results with sample identification are provided, and in addition data from previous work [13] are given for comparison. They show the same general leaching characteristics as found in the previous project using pH dependence leach test (in ANC mode). As example Figure 3.3 shows the results of this comparison for chromium. This illustrates that the same generic behaviour is found for Cr leachability from Portland cement mortars. In addition, the same special Cr behaviour of some mortars is found in previous as well as in the current work.

For many elements, the special cements W1 and W2 do not differ from the commercial Portland cements. The spiking is clearly identified for Cr, Mo, Zn, Sb and As. Since composition of cement D2 was the basis for the preparation of W1 and W2, a direct comparison between D2 and respectively W1 and W2 is made. In Figure 3.4 the comparison is shown for Cr, Mo, K and Zn. Although K has not been added, the lower K level in W1 and W2 compared to D2 is related to the fact that CKD was not mixed in with the raw clinker.

The test provides also information on the acid neutralisation capacity. This property in combination with field exposure properties acidification, carbonation and other sources of neutralisation dictate how long it takes for the surface of the specimen to be neutralised. This will then lead to another leaching characteristic.

The Acid Neutralisation Capacity (ANC) of cement-based products is high (Figure 3.5). Therefore only the surface of cement-based products can be neutralised and thus shows leaching characteristics corresponding to the neutral pH. In Figure 3.6 it is schematically illustrated, that element solubility is controlled by different conditions within the mortar and on the surface of a carbonated specimen. Since the surface is in direct contact with the surrounding environment, this condition is more determining for the release than the highly alkaline interior of the material.

Many other studies of cements and mortars have focussed on the behaviour of the highly alkaline matrix [30,31,32,33,34,35,36], whereas from a point of view of release to the environment the surface chemistry may prove to be more determining. This has in part be addressed by models such as the shrinking core model [37], which takes changes in surface chemistry and a moving pH boundary into account.

As carbonation is the main factor controlling pH change in cement-based materials, an issue to be resolved is to what extent pH control in the eluate by CO_2 instead of NaOH and HNO_3 will produce the same or slightly different results in a pH dependence test and in the tank leach test. In future work, this aspect needs to be addressed.

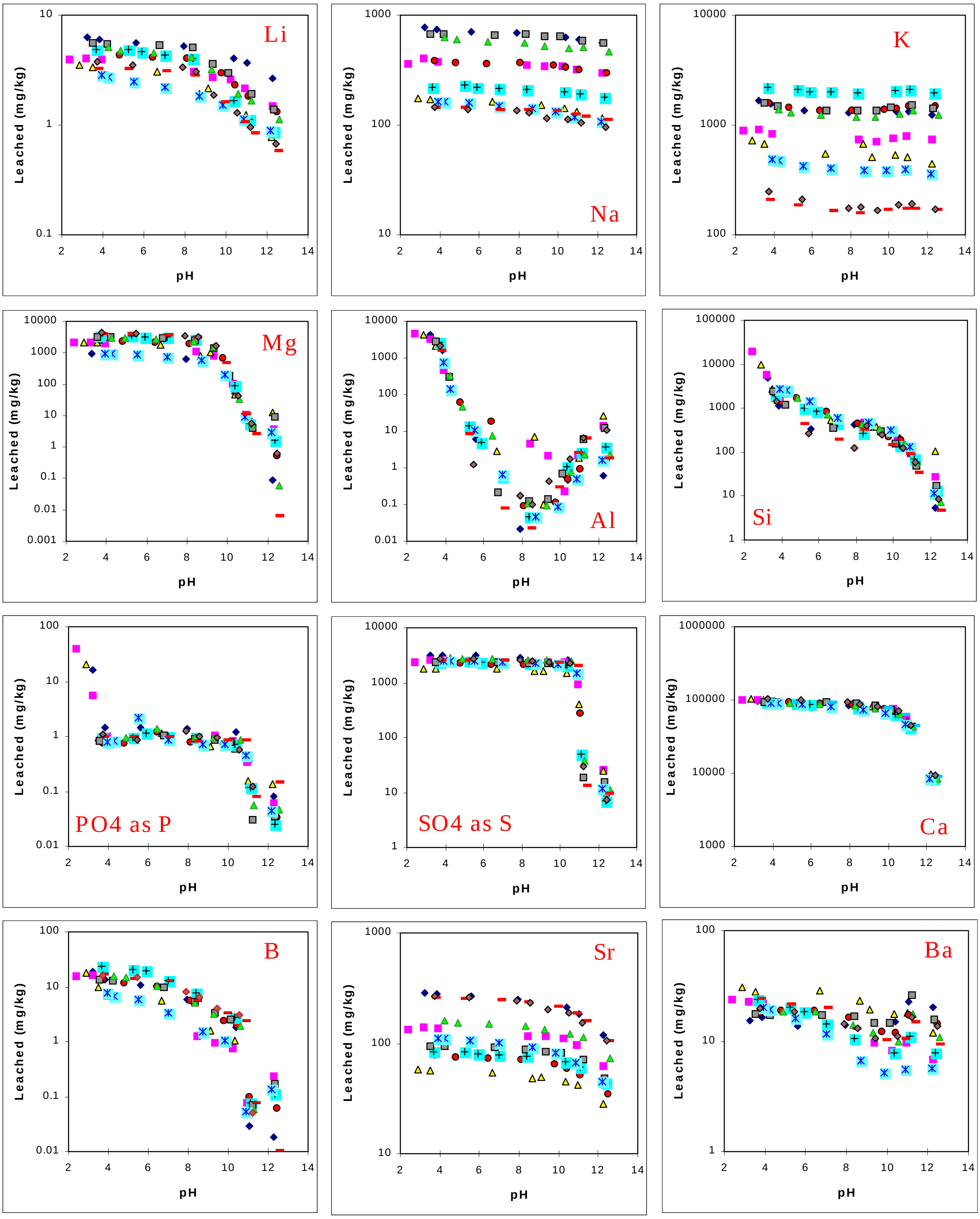


Figure 3.1. *Generic pH dependent leaching behaviour of major and minor elements from cement mortars (data from pH dependence leaching test on crushed mortar).*

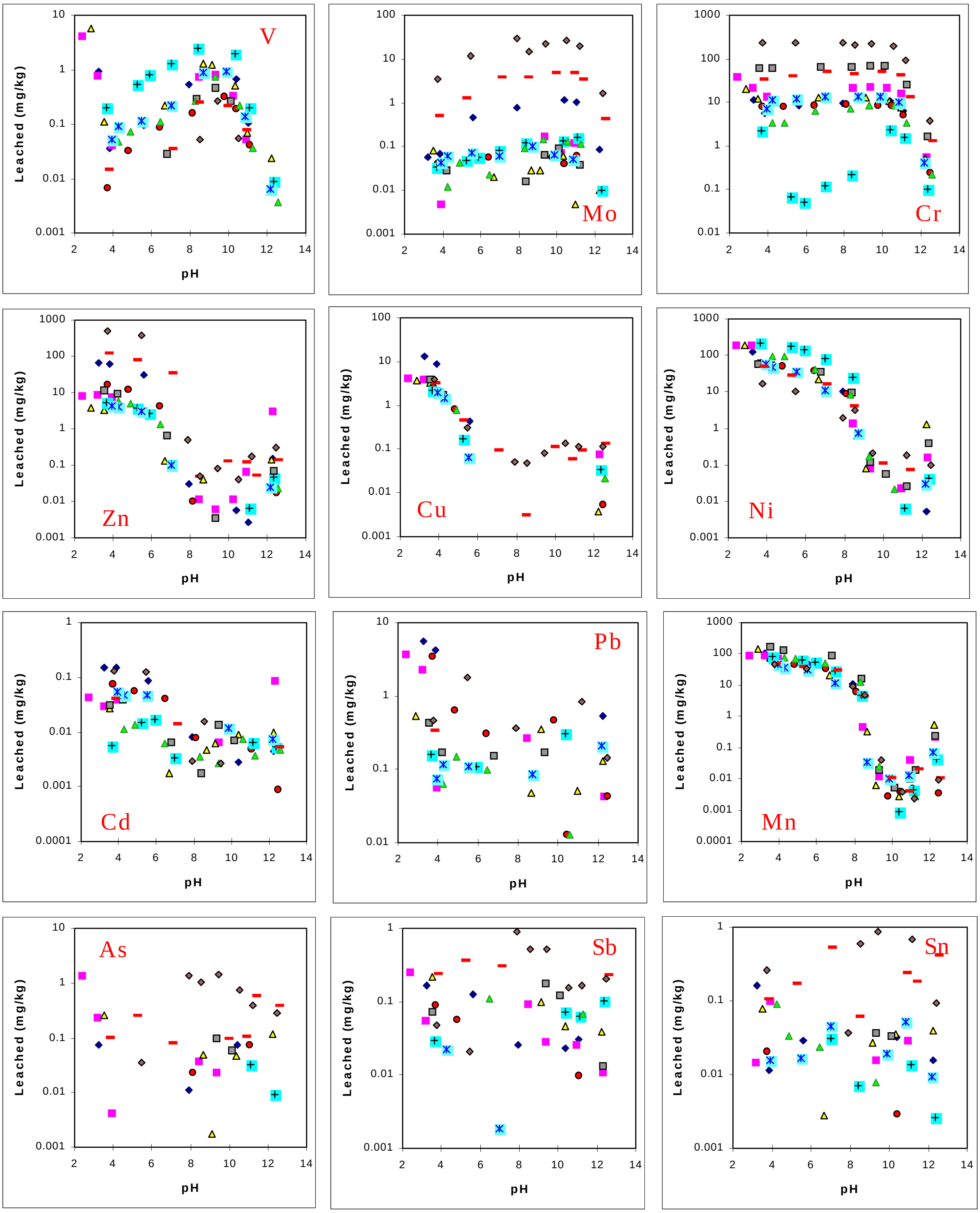


Figure 3.2 Generic pH dependent leaching behaviour of trace elements from cement mortars (data from pH dependence leaching test on crushed mortar).

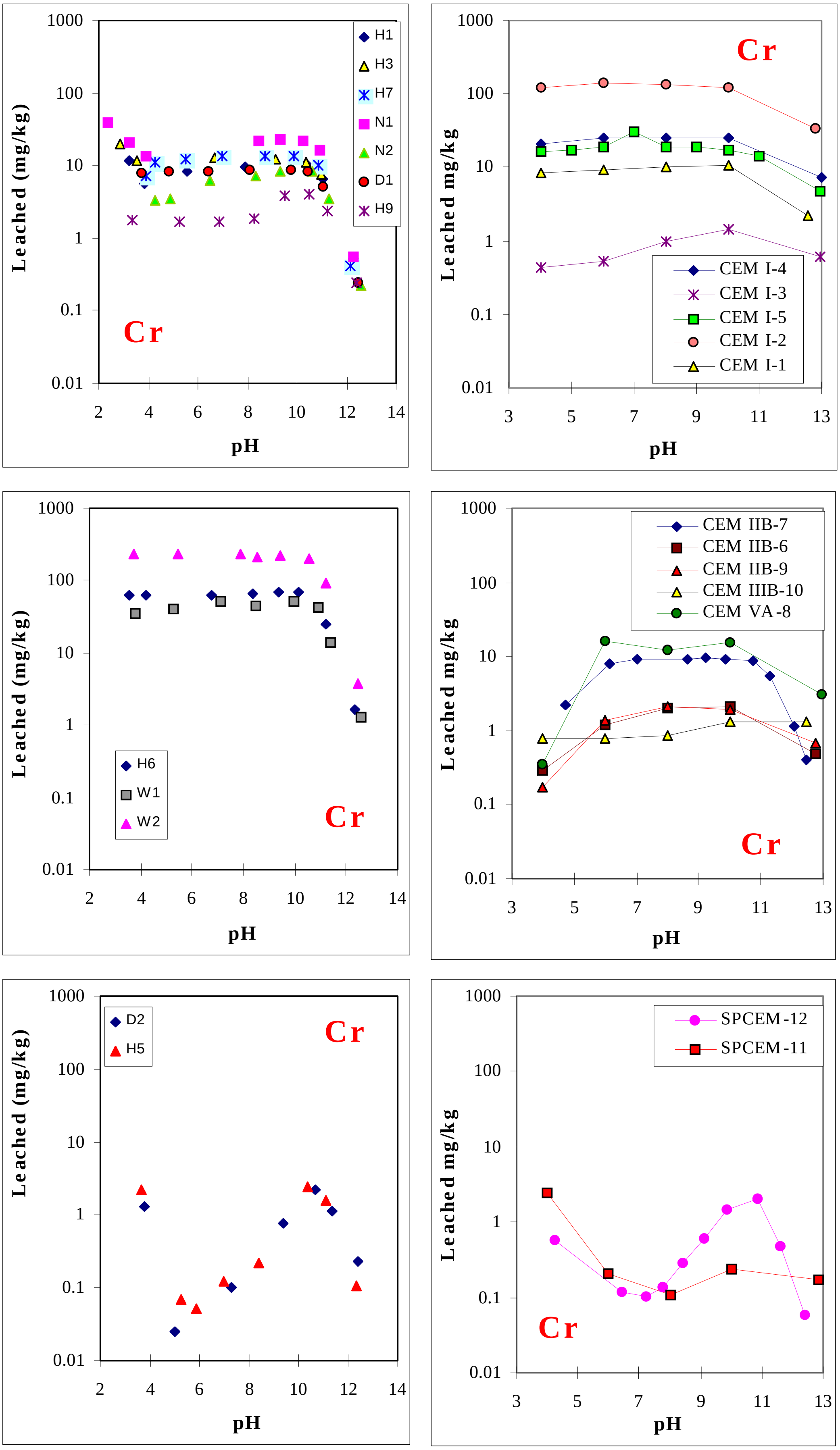


Figure 3.3 *pH dependence test data for Cr from present work (left) and previous work (right)*

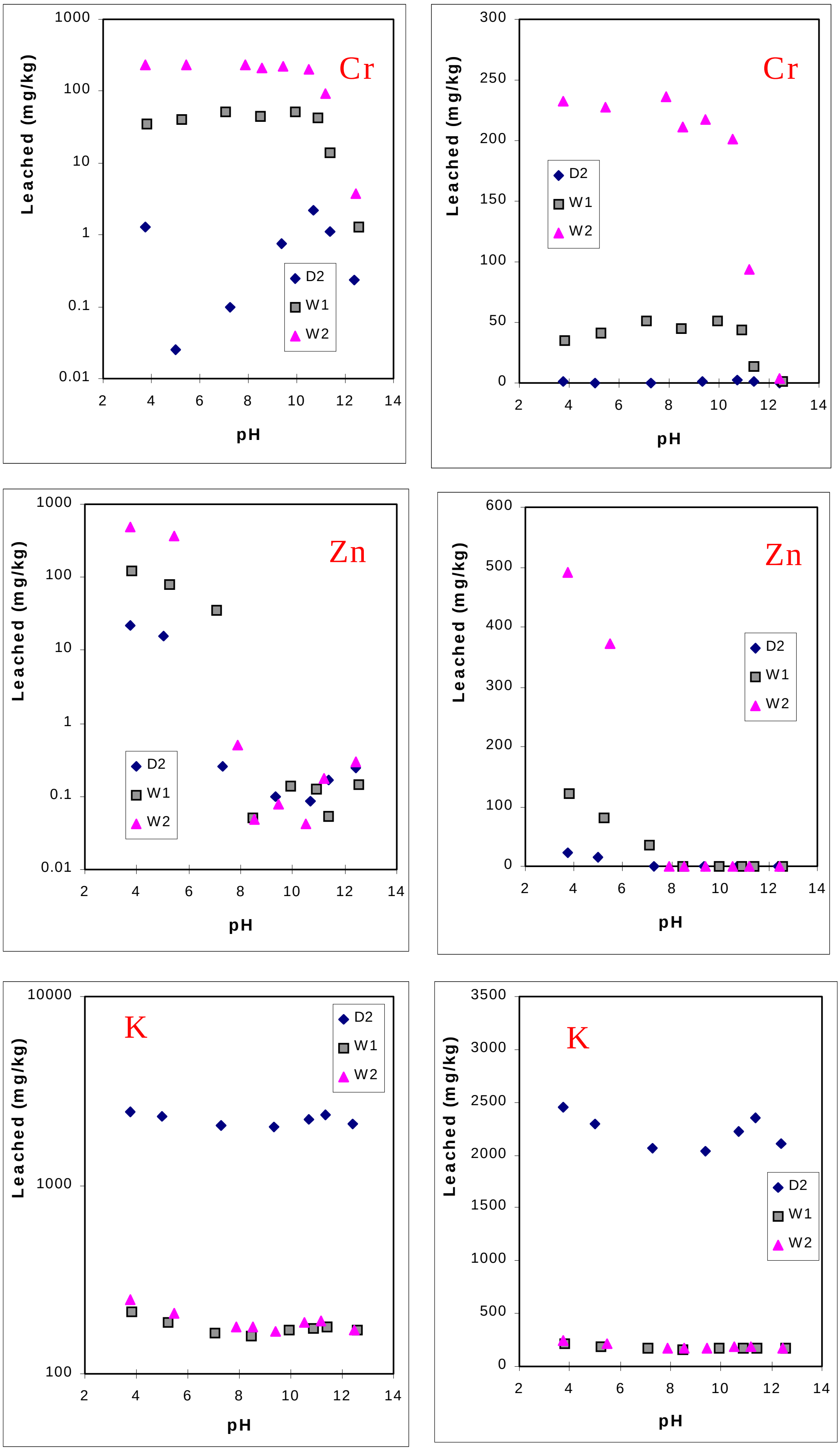


Figure 3.4 Comparison of W1 and W2 with D2, which formed the basis for the raw meal used in preparation of the special cements. Left: data on a log scale; right: data in a linear scale.

A clear distinction can be observed between the leaching behaviour of 'regular' metals (such as Pb, Cu, Cd, Ni and Zn) versus oxyanions (e.g. As, Sb, Se, Mo, V). The metals feature their highest leachability at very low pH and for some at very high pH (Pb, Zn). In contrast oxyanions show a leaching behaviour with low leachability at very high pH, a maximum leachability at neutral to mild alkaline pH and generally somewhat lower leachability at pH around 5. This behaviour is related to solubility controlling processes (to be discussed in relation to geochemical modelling, see section 3.7). The leaching behaviour of a few specific elements is discussed in more detail in relation to the modelling work. The leaching behaviour of major elements and most minor elements is very consistent between the various cements.

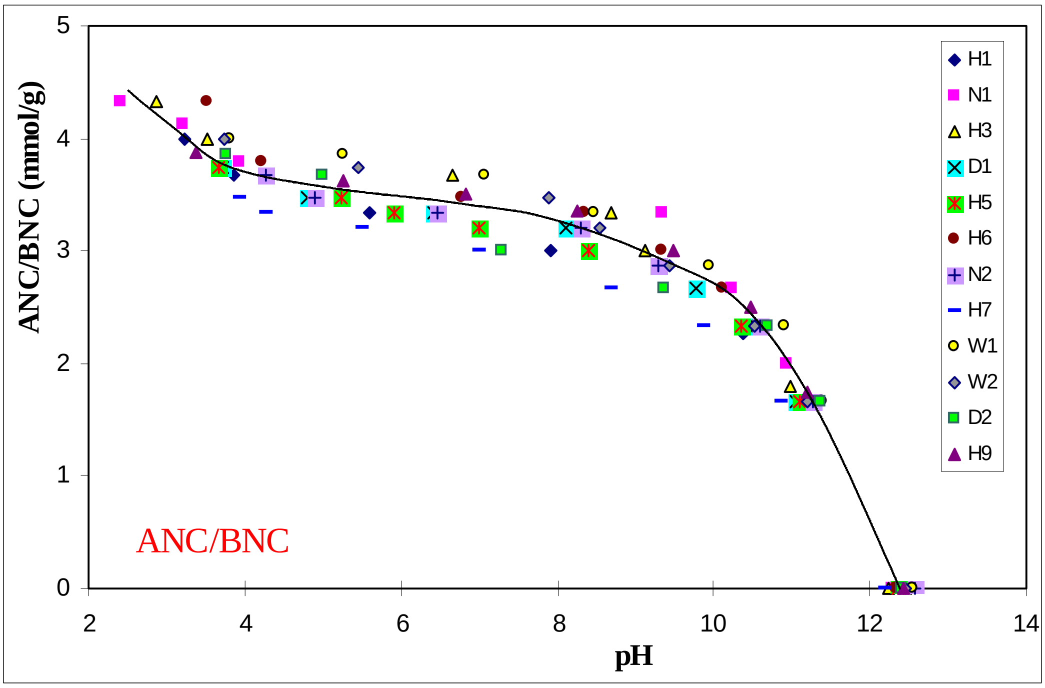


Figure 3.5 *Acid Neutralisation Capacity (ANC) for cement mortars (pH dependence leaching test)*

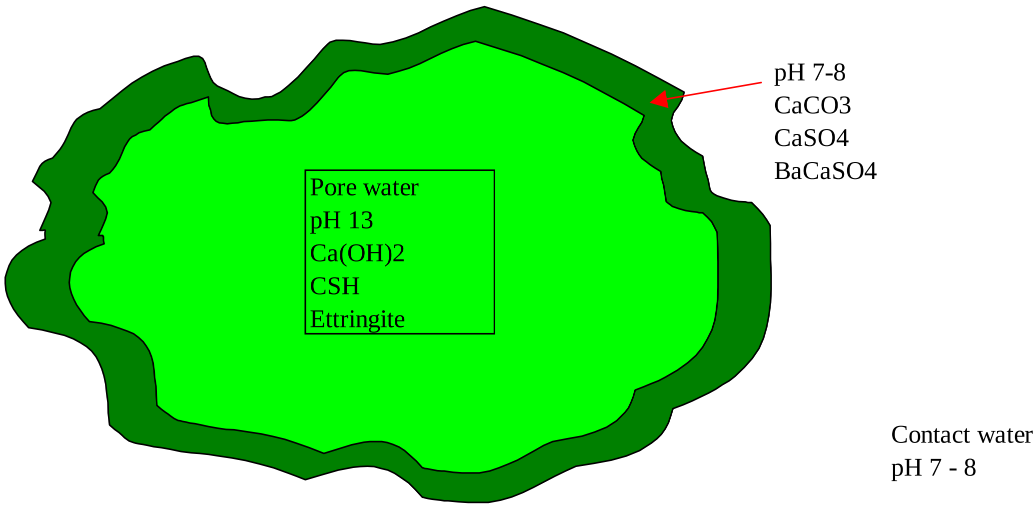


Figure 3.6 *Bulk versus surface chemistry in concrete. Thin surface coating of minerals dictates environmental properties.*

The leaching characteristics of the hardened cement mortars have been determined by examining the leaching behaviour as a function of pH in the pH range 3 -13, which has revealed very consistent and systematic leaching patterns, which are not as obvious from tank leach tests (dynamic leach test providing time dependent release information). The leachability in the pH range 5 to 13 is most relevant from an environmental point of view, as field exposure conditions may well cover this range.

The special “spiked” cements have leaching characteristics very similar to the other regular OPC‘s. The leached amount for elements occurring mainly as oxyanions (Cr, Mo, As, Sb) is increased.

Significant differences in generic leaching behaviour as a function of pH as determined in previous work for metals, oxyanions and salts have been reconfirmed. Metals generally show a minimum leachability at neutral pH. Oxyanions feature a maximum leachability at neutral pH, and salts show no relation with pH.

Similar to the situation on other fields, the pH dependence test forms a solid basis of reference for for mutual comparison of hardened cement mortars in various exposure scenarios.

A distinction must be made between the cement phases controlling the leachability of the bulk of the element present in the cement matrix and the solubility controlling phases dictating leachability of elements at the surface of the test specimen, which are exposed to external conditions (air, water, etc). The leachability amounts generally to a small fraction of the total composition.

3.6.2 Availability Test

In the Netherlands, the availability of the elements for leaching is assessed as a convention by NEN 7341 [17] (particle size < 125 micrometer; two test conditions: pH = 4 and pH = 7). The test results serve as ‘driving force’ in release models. In table 3.2 this availability for the cements tested in ECRICEM is given as percentage of the total contents in the mortar. Sand used in preparing mortars is generally not contributing to the leachable fraction significantly. The availability varies significantly from one cement to another. Only Sr availability is very consistent throughout all cement samples. The elements Cr, Co, Mn, Cu and Zn show a rather high availability for leaching. Almost all Sr is available for leaching. There is no systematic trend by element. Values exceeding 100 % can occur as a result of comparing two numbers with each their own analytical uncertainty. The high value for Cd (163 %) is caused by the rather low Cd level in mortar, which results in rather high analytical uncertainty of both total and availability. From an analytical performance point of view values exceeding 100 by about 10 % are acceptable. Availability values for W1 and W2 are not significantly different from the other cements. Ni data are missing from the table as the data are not consistent with the total composition data, since more than 100 % availability was observed. Some form of contamination may have occurred. This needs to be verified in ECRICEM II.

Table 3.2 *Availability expressed as percentage of the total composition (mortar)*

	H1	N1	H3	H5	H6	D1	H7	N2	W1	D2	W2	H9	Average	Stdev
As	4.1	24	44	3.6	7.0	3.4	0.0	0.0	2.3	34	1.7	24	12	15
Ba	32	99	55	97	47	39	86	46	83	89	49	42	64	25
Be	0.0	0.0	0.0	0.0	22	0.0	0.0	36	52	0.0	56	0.0	14	22
Cd	64	166	73	41	28	49	42	14	52	0.0	43	80	54	42
Co	87	98	93	145	60	97	64	93	98	108	37	131	93	30
Cr	51	83	89	22	49	46	42	48	62	30	68	48	53	20
Cu	100	104	92	50	58	66	49	43	56	69	73	107	72	23
Mn	83	96	88	76	36	31	56	83	103	113	82	101	79	26
Mo	123	36	0.0	0.0	0.0	3.5	0.0	11	44	103	58	27	34	42
Pb	35	72.	18	6.0	8.8	13	15	2.0	2.7	66	55	60	30	27
Sb	14	48	0.0	0.0	0.0	30	0.0	0.0	19	39	12	30	16	17
Sn	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31	3.0	
Sr	94	101	105	109	100	101	95	96	96	96	97	99	99	4
V	3.8	38	31	4.4	5.1	4.1	11	9.7	4.2	13	3.9	8.3	11.	11
Zn	70	66	47	45	56	64	59	53	98	68	97	166	74	34

* Ni not shown, as it is affected by contamination from the size reduction process.

The comparison of the end of life conditions reflected by full carbonation and size reduction indicates that under these worst case conditions significantly lower leached quantities (Table 3.3) are observed than in comparison with the availability data (Table 3.2). These conditions can be seen as different worst case estimates, which are both better alternatives for judgement than total composition. Experiments were not carried out on fully carbonated material. The pH control is used to reflect the major pH effect resulting from carbonation.

Table 3.3 Leachability in a batch test (L/S=10, pH =8 control) relative to total concentration (in %)

	H1	N1	H3	H5	H6	D1	H7	N2	W1	D2	W2	H9	Average	Stdev
As	0.2	0.2	2.2			0.3			0.1		0.4		0.5	0.8
Ba	4.9	10.9	10.2	10.7	7.6	8.3	12.1	8.8	17.2	15.7	8.9	10.6	10.5	3.4
Cd	0.9		3.1		0.3	1.3		0.9	4.4		0.2	3.2	1.8	1.6
Co	2.2		0.2	2.6	0.9	3.7	6.1	2.8	13.4	10.6	1.3		4.4	4.4
Cr	10.6	11.7	14.0	0.5	11.5	11.6	10.6	10.3	15.3	0.3	16.9	5.5	9.9	5.3
Cu									0.4	0.3	0.2	0.2	0.3	0.1
Mn	2.2	0.1	0.0	1.1	0.9	0.8	3.5	3.5	14.8	11.0	4.0	0.4	3.5	4.7
Mo	20.6	4.8						1.8	8.6	11.7	14.4	-0.2	8.8	7.4
Pb		1.3	0.4		0.00			-0.8			2.8	0.9	0.8	1.2
Sb	0.5	4.4							4.0		3.0		3.0	1.7
Sn	0.3												0.3	
Sr	20.3	21.4	22.0	24.6	23.3	22.9	21.3	21.0	22.8	22.3	22.0	22.2	22.2	1.1
V	0.5	1.7	1.8	1.1	0.8	0.5	0.6	0.9	0.1	1.2	0.0	1.5	0.9	0.6
Zn	0.01	0.02	0.13			0.01	0.34		6.9	0.2	0.0	0.1	0.9	2.3

In table 3.4 a comparison between leached and total concentrations is made for the tank leach test. In this case, the release expressed in mg/m2 is extrapolated to100 years (assuming diffusion control factor 23.6 = √35600/64) and recalculated to mg/kg. This number is calculated as a percentage of the total. This number is only valid for the specimen size tested (16x16x4 cm). For larger specimen this number will be progressively lower as release from a monolith is surface area related.

Table 3.4 Leachability in the tank leach test (100 y) relative to total concentration (in %).

	H1	N1	H3	H5	H6	D1	H7	N2	W1	D2	W2	Average	Stdev
As				0.001	0.0029					0.0001	5E-06	0.001	0.0013
Ba	0.0062	0.0293	0.0136	0.0223	0.0157	0.0193	0.0352	0.0125	0.0252	0.0125	0.0196	0.01922	0.0084
Cd	0.0014	0.0037	0.0081	0.0046	0.0029	0.0033	0.0036	0.0032	0.0038		0.0002	0.00346	0.002
Co	0.0029	0.0038	0.0011	0.0023	0.0007	0.0032	0.0023	0.0016	0.002	0.0021	0.0013	0.00212	0.0009
Cr	0.0021	0.0007	0.0011	0.0058	0.0021	0.002	0.0009	0.0006	0.0016	0.009	4E-05	0.00237	0.0027
Cu	0.0008	0.0023	0.0025	0.0015	0.0012	0.0039	0.0025	0.0028	0.0016	0.0014	0.0063	0.00244	0.0015
Mn	3E-05	1E-05	2E-05	2E-06	3E-06	2E-05	4E-05	4E-05	8E-05	2E-05	2E-05	2.5E-05	2E-05
Mo	0.0017	0.003				0.0057		0.0012	7E-05	0.0056	2E-05	0.00246	0.0024
Ni	0.0012	0.0014	0.0013	0.0017	0.0013	0.0007	0.0015	0.0012	0	0.0061	0.0015	0.00163	0.0015
Pb	6E-05	0.0002	0.0009	8E-05	0.0002	8E-05	0.0004	0.0001	5E-05	0.0003	0.0006	0.00027	0.0003
Sb	0.0003	0.0003				0.0032			0.0002	0.0003	0.0004	0.00078	0.0012
Sn	0.0034											0.00336	
V	0.0014	0.0016	0.0014	0.0005	0.0023	0.0054	0.0046	0.0034	0.0049	0.0042	0.0046	0.00312	0.0017
Zn	0.0769	0.5898	1.1635	0.4287	0.2999	0.3672	0.8497	0.8024	0.069	0.3607	0.0285	0.45785	0.3622

3.6.3 Tank Leach Test

The tank leach test according to NEN 7345 has been applied to assess the release from monolithic specimen both under own pH (generally pH > 11 in eluate) and under imposed neutral pH. The latter situation is more relevant for cement-based products in contact with natural surface water, where the external neutralisation surmounts the supply of alkalinity from within the matrix. The difference between own pH and imposed neutral pH has been evaluated. In Figure 3.7 the difference is illustrated for Cd and Pb for example, which show a higher leachability at neutral pH than at high pH. Irrespective of the regulatory limit values, the 10 times lower release levels at own pH do not apply to conditions where neutralisation will take place. Not in all cases the leachability increases with decreasing pH. The pH dependence test data indicate the direction and the approximate magnitude of change as a result of neutralisation. This applies also for neutralisation by carbonation.

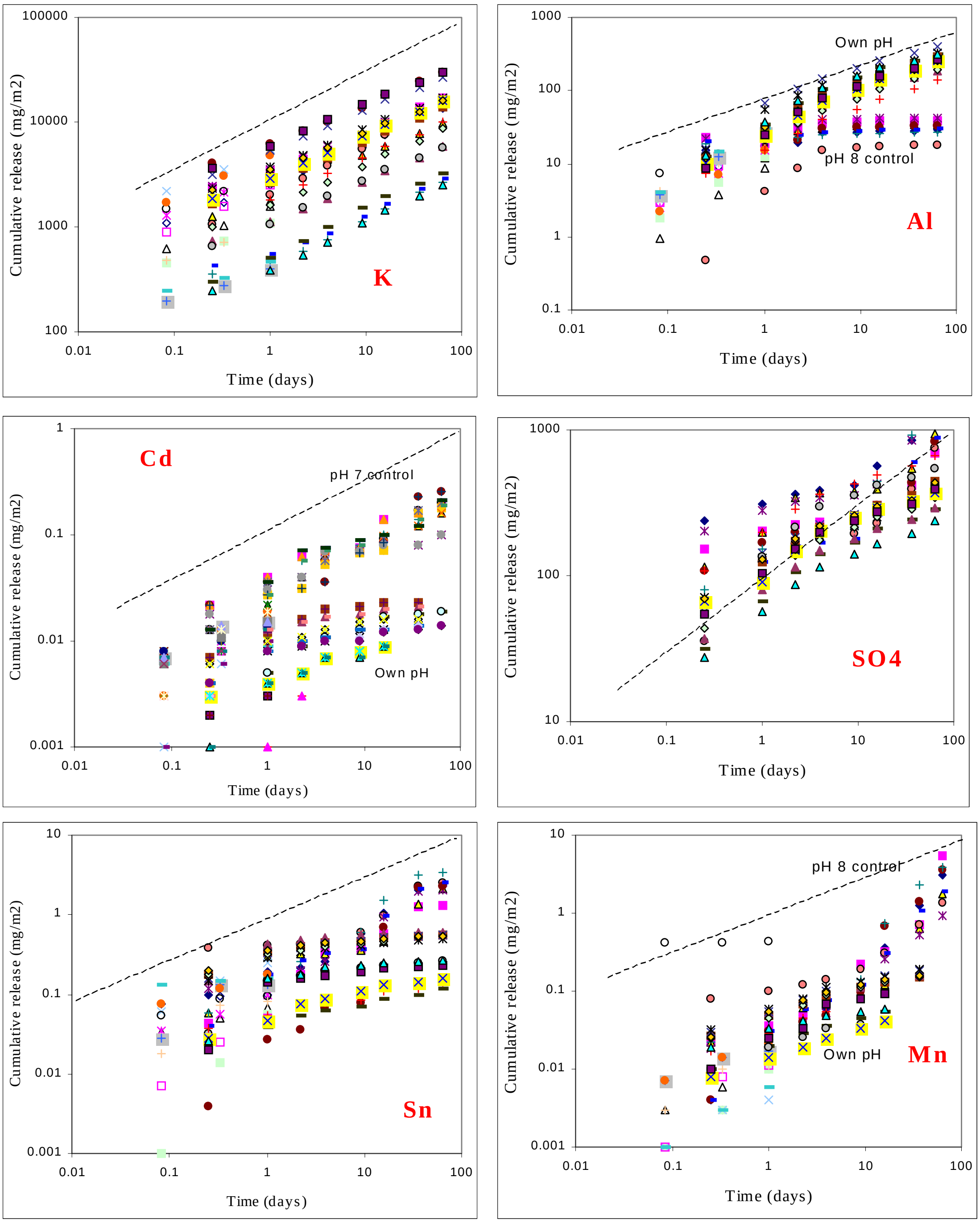


Figure 3.7 *Release of major, minor and trace elements at 'own pH' and imposed 'neutral pH' in the tank leach test.*

The tank test data reflect that release as observed in cement mortars generally appears to be diffusion controlled, although not all elements will show this type of release in all cases. Time dependent release curves may reflect a number of different situations:

- diffusion behaviour (slope 0.5 in cumulative release - time plot) - e.g. K
- depletion of soluble species, when the dimension of the tested specimen is rather small such that a very mobile species can be leached completely - e.g Al at neutral pH and Cd at own pH.
- delayed release may occur, when a solubility controlling phase is limiting the release of a given constituent in the initial phase of leaching - e.g Al.

- wash-off occurs, when in the first or first two eluates of the test an increased release is noted - e.g sulphate.
- chemical changes may occur during the testing period, such as a change in redox state in the surface of the matrix or a change in pH such that the leachability of specific components is affected significantly - e.g Mn.
-

The latter changes can be anticipated from the pH dependence test. Figure 3.8 gives graphic examples of such different release behaviour.

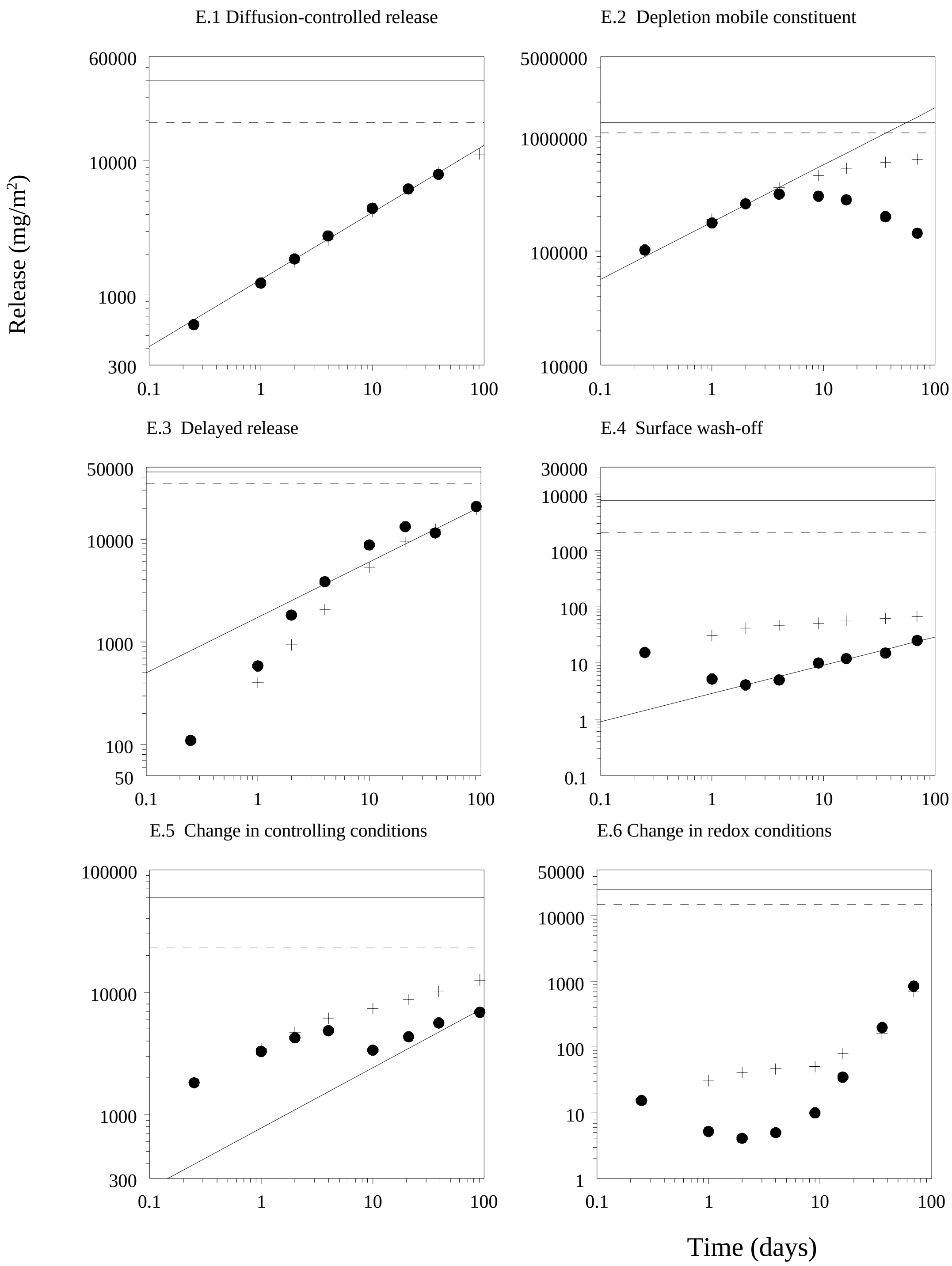


Figure 3.8 Different types of release behaviour from monolithic specimen in the tank leach test. The horizontal drawn and dotted line represent the total and the availability for leaching expressed as mg/m2 (this unit implies the data is specific to the specimen dimensions tested). The sloped line (0.5 slope) reflects theoretical diffusion. The plus symbols reflect the cumulative release using all previous fractions for calculation. The dots reflect the theoretical release, if the release rate for the interval is used for the entire period up to that of the measurement interval.

From the tank test data, tortuosities for the different cement mortars can be derived. The tortuosity τ^2 describes the relation between the free mobility of a substance in water compared to the free mobility in the pore system of the mortar. Therefore the tortuosity is a measure for the porosity of the mortar, as it represents the tortuous path a diffusing ion (Na) has to travel through the matrix to reach the surface of the specimen. In table 3.5 the tortuosities calculated from Na free mobility (assuming no retention in the matrix) for the mortars prepared from the different test cements are given. In comparison with the microstructural analysis very similar data on the cement mortars are obtained. N1, H6 and H1 are indicated as being least porous. H5 is the most porous from a microscopical observation, which is confirmed by the tortuosity measurement.

Table 3.5 *Tortuosities calculated from Na mobility*

Code	τ^2	Code	τ^2
H5	250	H7	370
D2	270	N2	400
W2	310	N1	500
W1	370	H6	500
D1	370	H1	530
H3	800	H9	710

From the tank leach test effective diffusion coefficients for the mortar can be derived, which within certain assumptions allows prediction of release at longer time-scale than measured in the lab. The effective diffusion coefficients (expressed as $pD_e = -\log D_e$; De in m^2/s) can only be used together with the corresponding availability data (in mg/kg mortar). Table 3.6 gives the effective diffusion coefficients and the availability data for the mortars prepared from the different test cements. The availability data obtained for the spiked special cements are not included for all elements in calculating the average, as the values for Al, Cr, Mo and Zn would not be representative for commercial cements. For other elements the data are within the range obtained for commercial cements.

Using these data as starting point predictions can be made of release in long term (see section 3.9). Either the ‘own pH’ test data or the ‘neutral pH’ test data are used, depending on the exposure condition of the construction product (see discussion in section 3.6.4).

Significant differences in pDe for ‘own pH’ and ‘neutral pH’ indicate that the release will be different, when the material is dictating the pH in its immediate environment or when external factors cause the pH at the surface of the material to be neutral (common case). A higher value of pDe will indicate a lower release. Examples of elements with a higher leachability at neutral pH are: Cd, Mo, Sb, V and Pb.

Table 3.6. *Effective diffusion coefficients and availability data for the mortars prepared from the different test cements (pDe = -log(D_e) with D_e in m2/s)*

	pDe at pH 7-8		pDe at own pH		Availability (mg/kg)*		
	Average	Stdev	Average	Stdev	Average	Stdev	%
Al	16.32	0.42	15.15	0.67	2460	1335	54
As	9.77	1.65	13.53	2.32	0.16	0.12	74
Ba	13.42	0.25	12.67	0.38	21.08	4.55	22
Ca	14.63	0.22			97183	3531	3.6
Cd	11.69	1.20	13.20	1.12	0.05	0.06	110
Cr	14.48	0.98	14.42	0.58	7.87	7.48	95
Cu	15.52	0.60	14.89	0.50	4.82	4.43	92
K	11.31	0.20	11.18	0.14	1701	557	33
Mo	10.82	1.57	11.45	1.11	0.029	0.022	77
Na	11.43	0.38	11.44	0.12	446	211	47
Pb	11.62	1.60	15.44	0.97	2.35	2.09	89
S	15.28	0.29			2644	299	11
Sb	10.68	1.21	13.78	1.18	0.11	0.07	68
V	12.07	1.37	14.14	1.53	0.33	0.42	126
Zn	16.03	1.35	15.47	1.51	20.9	23.4	112

*All cements with exception of spiked cements (too high available quantity)

Deviations in W1 and W2:

	pDe at pH 7-8		pDe own pH		Availability	
	W1	W2	W1	W2	W1	W2
Al	17.6	17.9	14.08	15	1661	2223
Cr	16.09	16.52	14.97	15.34	232	34.5
Mo	12.43	13.62	12.22	12.31	0.51	3.42
Zn	16.75	18.6	17.0	18.27	122	491

The tank test data carried out at own pH and pH controlled at around 8 indicated first that the leaching behaviour under these test conditions is very consistent. The release is in several cases close to the theoretical diffusion control. In some cases where the leachability is strongly affected by a minor change in pH (sulfate, oxyanions at high pH) the release is affected by pH changes during the test. The combination of pH dependence test and tank test is needed to be able to draw such conclusions. In that sense the methods are complementary in nature.

3.6.4 Compliance Test (Monolith)

In Figure 3.9 tank leaching test measurements on monolithic samples at own pH are given. The figures show 64 day release for barium (left) and chromium (right). In the figures the measured results of the long term (64 days) tank leaching test are compared with calculated 64 day values, the latter values were extrapolated from the short term monolith compliance (2 days) tank leaching test by assuming diffusion controlled (√t) behaviour. As can be seen, these extrapolated data give a quite good indication of the actual release after 64 days. However, an accurate long-term release can only be derived from the full 64 day test. Thus, when reducing the test time significantly educated guess of the long-term behaviour can only be made once the general leaching behaviour of the specific elements are known.

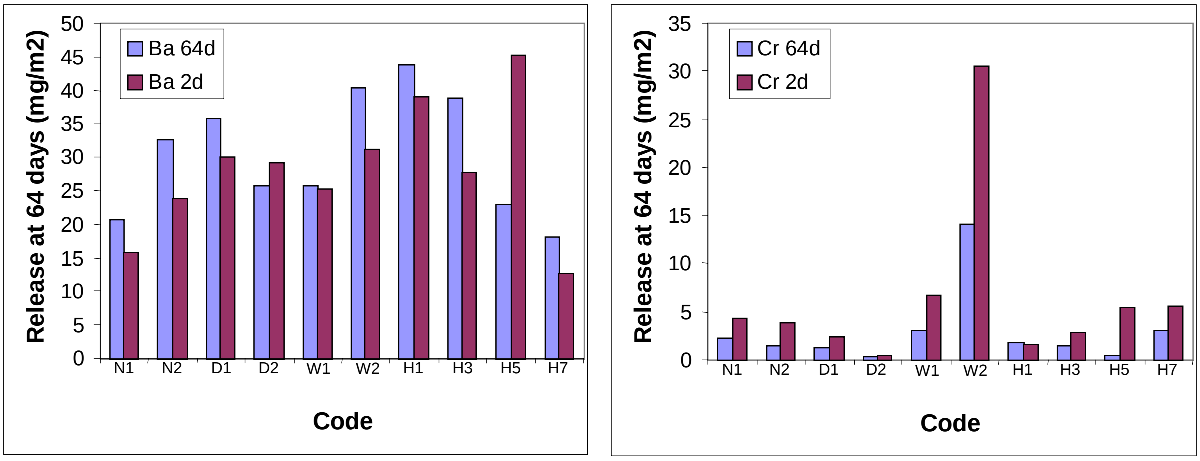


Figure 3.9 *Long term release (64 days, own pH) for barium (left) and chromium (right). The calculated data are extrapolated from a short compliance (2 days) leaching test assuming diffusion controlled behaviour.(Data for short tests on H6 and H9 not determined)*

3.6.5 Concise Test

The concise test is carried out on crushed material and is relevant for an evaluation in conjunction with the long-term behaviour of size reduced materials (construction debris) with neutralisation by carbonation and percolation dominated release regimes [19]. The 4 steps of the concise test address each of these issues:

- Two extractions at own pH using low (L/S=2) and high L/S (L/S=10). These results give an indication of solubility controlled species versus species being washed out easily. The low L/S reflects a relatively short time scale and L/S=10 reflects a long-time scale. The results of this part of the test are discussed in connection with the porewater data.
- Two further steps comprising leaching tests at L/S = 10 and pH 7 (in this study pH 8) and pH 4. The results from these tests are linked to the pH dependence test data. The pH = 7 measurement is relevant to identify the direction and magnitude of change in leachability as a result of neutralisation by carbonation. The pH 4 measurement provides a measure for the availability for leaching. In comparison with the total composition, this value, which is generally a fraction of the total, can be considered as a worst case environmental exposure condition.

Although the measurement should originally be carried out at 2 mm size reduced material [19], it has been done in this study on material with an artificial particle size distribution (0 - 10 mm; leaching time 24 hours). This hampers the originally intended comparison, but has brought a first quantitative impression of the effect of particle size on leachability. Thus, this ‘adjusted concise’ test for L/S = 10 is comparable to the compliance test (EN 12457-4) in which pH dependence has been included and agitation is changed to magnetic stirring. Figure 3.10 gives a comparison of the ‘adjusted concise’ (compliance) test data with the pH dependence test and the availability test data.

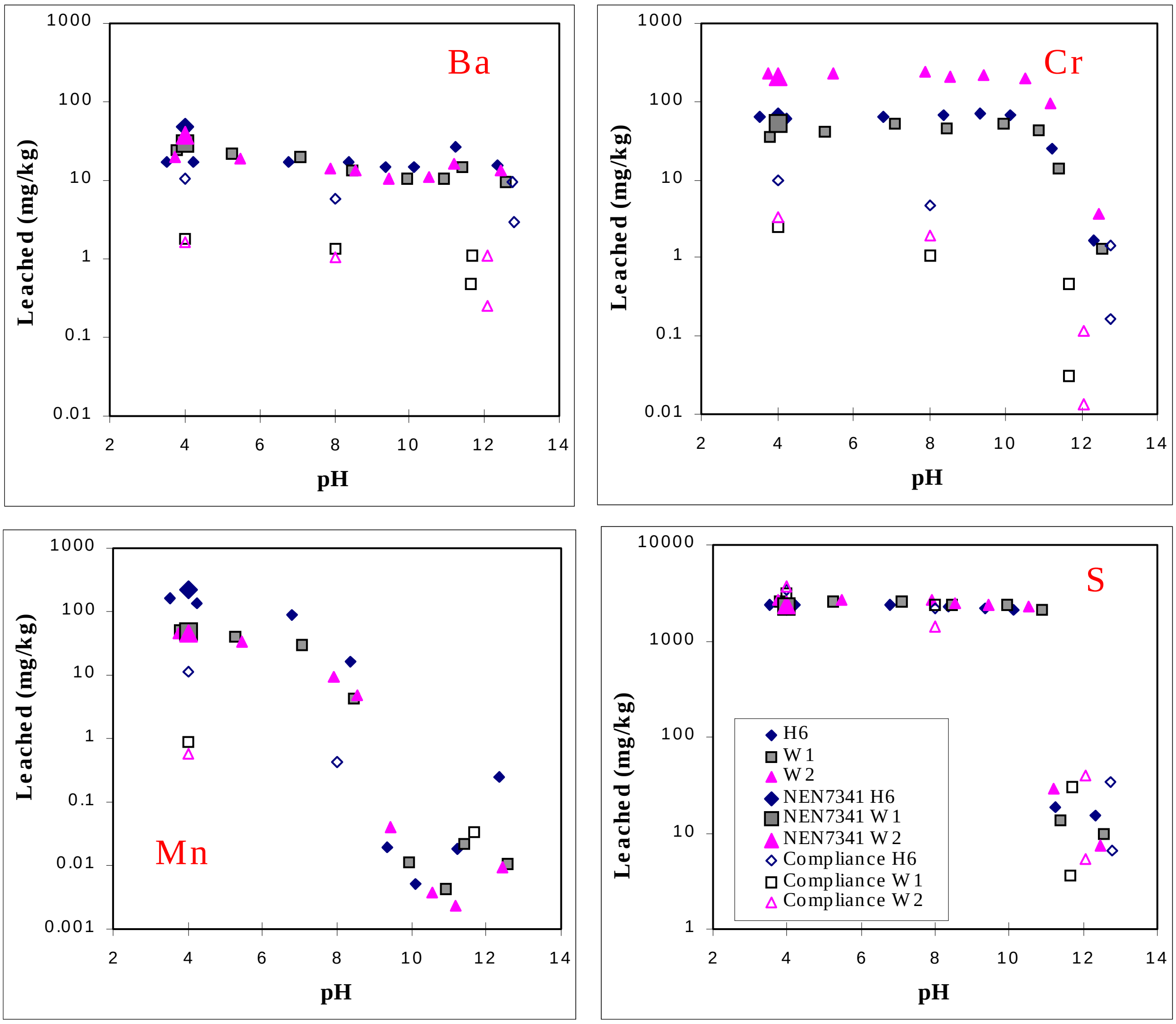


Figure 3.10 *Comparison of 'adjusted concise' (compliance) test data with pH dependence test and availability test data (NEN 7341). Note: particle size distribution for pH dependence test and 'adjusted concise' test were not the same*

Figure 3.10 shows, that in case of solubility control, the difference between the different test results is small (SO4 as S at controlled and own pH). As soon as leachability from the interior of the particles governed by diffusion comes into play the size distribution and the contact-time become important controlling parameters. If for a larger particle size longer contact time is allowed more comparable results are obtained. The aspect of relevant particle size for testing is a key issue that needs to be addressed in the future work as a larger particle size generally leads to less repeatable results in testing. On the other hand the release as obtained from size reduced material may overestimate the actual release for material, that in its application is not fine-graded. A balance between both aspects – repeatable and relevance – needs to be reached.

Significant differences between small particle size and coarser graded material (latter more relevant for construction debris evaluation) has been observed. Further work is needed to address the complex issue of finer, fully carbonated material next to superficially carbonated material with a core of high alkalinity. A scenario approach through modelling, testing separate fractions and combined fractions is needed to identify the ANC balance between sub-fractions to conclude in which circumstances fines or the coarser fraction dominate release.

3.6.6 Pore Water Tests

The pore water data were obtained by pressing water out of hardened mortar bars with a powerful press. This results in very small volumes, which limits the number of constituents that can be measured. In spite of this limitation, very useful data have been obtained. The data from the concise test and the pore water form a series of L/S values, that provide insight into the chemistry changes at low L/S (high salt load, larger pH differences).

In Figure 3.11 the measured concentrations of Cr (almost exclusively Cr VI) and Ca are given as a function of L/S value. From the fact that the concentration of Ca increases almost proportional to L/S (slope 1 in concentration - L/S plot; given as a dotted line), it can be concluded that Ca is solubility controlled over the entire L/S range. From the fact that the slope from Cr is horizontal or even negative for low L/S values it is clear that its release is diffusion controlled. It is also clear from the figure that the Cr concentration in the pore water and the leachate are approaching a equilibrium, because the release increased when higher amounts of leaching water are offered (higher L/S values).

The data at L/S =2 and L/S=10 are based on mortar crushed to < 10 mm. This explains the difference between the release level at L/S =10 in this comparison and in the pH dependence test data discussed earlier. If data on further size reduced material would have been used the conclusion would be the same, as both L/S=2 and L/S=10 data would shift roughly parallel.

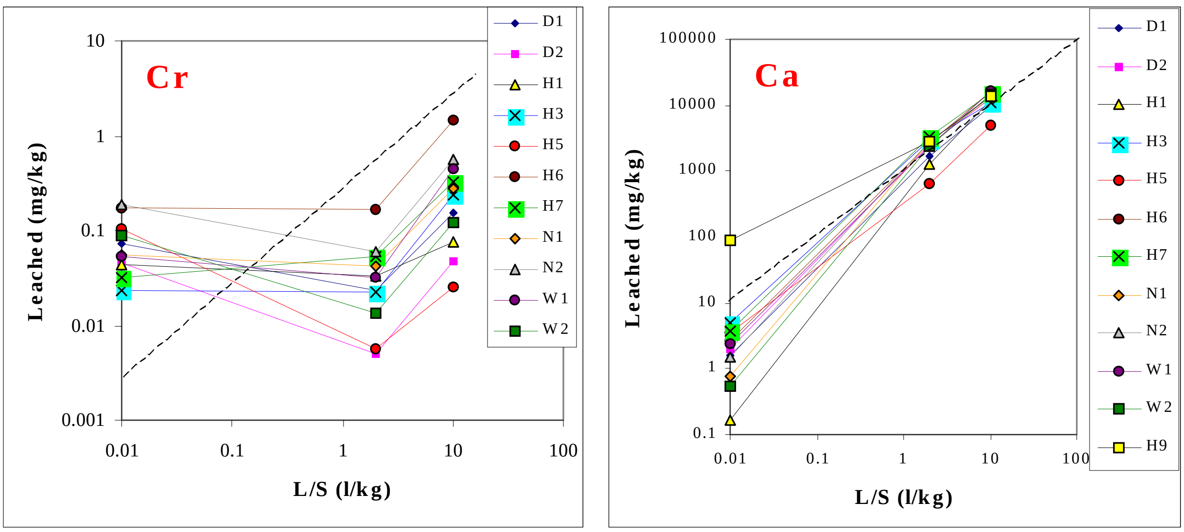


Figure 3.11 *Leachability of cement mortar as a function of L/S illustrating solubility control for Ca and largely dissolution for Cr (chromate). The dotted line represents solubility control. Data from porewater test (L/S=0.01) and from concise test (L/S=2 and 10). (Data for Cr on H9 not measurable).*

An alternative and less costly means of obtaining pore water in larger quantities is to apply a serial batch test with solids renewal instead of liquid renewal, which is the most commonly applied technique. After each cycle of solids addition the effective L/S is reduced by a factor 2. A L/S ratio of 0.1 can thus be obtained providing several 10 ml's of test solution depending on the weight used per step. It is worth verifying this alternative means of assessing the same useful property.

Pore water measurerments are useful. However, the method applied provides too little liquid for proper analysis. Alternative option to obtain a representative pore water sample is by applying a serial batch with solid renewal.

3.6.7 Relationships between Test Methods

All leaching tests are conventions, by which leaching is examined under the specific conditions of the individual test. For example compliance tests provide short-term testing of monolithic or granular samples. Full characterisation tests provide longer-term information on granular materials under various pH conditions. The different tests can individually and complementarily contribute to the overall understanding of the leaching behaviour. At the end only through modelling it will be possible to describe this leaching behaviour under certain environmental exposure conditions. A single test, however, can give certain information if the general leaching behaviour of a trace element is known. Therefore, it is important to know, how the different test results are related to each other.

The magnitude of change in leachability in the pH dependence test is to a large extent reflected in the change in leachability from a monolith in a tank test exposed to different chemical environments. However, while the pH dependence test is aimed at steady state conditions, the tank leach test reflects the dynamic aspects of leaching due to the 8 fold change of leachant during the test.

In table 3.7 a comparison is given of differences in release in the tank leach test between pH 8 and the own pH (generally in the eluate 11-11.5; for the cement matrix pH >12) and pH dependence test data between pH 8 and pH >12 and pH 8 and pH ~11, respectively. A number smaller than 1 points at a higher release at high pH (Al, Zn). Although a direct conversion is not possible the trends as observed in the pH dependence test can definitely be recognised and even to a large extent quantified in the tank leach test. This type of consistency would be expected, but given the variability within leaching tests it is good that it has been confirmed.

Table 3.7 *Comparison of pH effects between tank test (own pH and pH control at pH=8) and pH dependence test*

	Tank test	PH dependence test	
	Ratio pH8/pHown	pH8/pH>12	pH8/pH11
Al	0,07	0,04	
Co	5,12	4,90	
Cr	0,88	21,29	1,13
Fe	1,34	2,29	
Mo	4,30	10,61	0,74
Na	1,02	1,20	1,11
P	23,21	22,92	6,69
S	1,17	218,15	22,39
Si	13,59	41,91	4,65
V	117,54	146,73	
Zn	0,27	0,45	

The difference between tank leach test results at own pH and controlled pH is significant for several elements (Al, Pb, Cd, Sb, Cr, Mo). In the judgement of the exposure conditions in a given application this aspect has to be factored in.

3.7 Modelling

The modelling of geochemical reactions in cementitious materials forms the basis for the prediction of a long term release of constituents. The understanding of the solubility controlling factors will provide a basis for predicting long term behaviour and as such can be used as a means to set limits for the input of specific constituents in clinker.

Geochemical Modelling:
In geochemical modelling the measured concentration of major, minor and trace elements together with pH and, if relevant, redox info is used as input to MINTEQA2 or ECOSAT [22,23]. In the model an iterative process is started to calculate matching equilibrium conditions using existing stability constants for well-defined mineral phases (large number of minerals in the associated database). The output of the program is a list of saturation indices (SI value) for element-mineral combinations. This allows a comparison of the extent to which a given mineral phase may be controlling solubility of a particular element. An SI close to 0 is indicative of possible solubility control. Generally, a range of measured pH values should show SI values approaching 0. A single data point is insufficient. Over the entire pH range from pH 4 to 12 a few mineral phases may be relevant. SI values between +0.5 and – 0.5 (factor 2 in concentration) are considered a good match.

The geochemical modelling focuses at the phases in hardened cement paste that are relevant from a leaching point of view. It should be realised that the external conditions of cement products exposed to the environment largely determine the release. The material may have a very high buffer capacity, but, if that buffer capacity is supplied in a very slow rate, the surface may become neutralised and as such reflect leaching behaviour under neutral conditions rather than behaviour in a high pH environment.

The modelling of cement chemistry has traditionally been focused at the high pH environment relevant for the cement paste. However, in environmental modelling the surrounding is important as well and in some cases more determining. In addition, as stated in the previous work [13,29], release in the normal service life of cement-based products is for most constituents very limited. Most cement-based products will be recycled at some point in their life cycle, at which point they may be size reduced and may be carbonated to a large extent as a result of the larger exposed surface area. The size reduction and neutralisation are conditions that reflect changes in the leaching behaviour that are better described with the modelling in the pH range 7 – 12 than with high pH cement phases only [29]. E.g. ettringite considered to be active in retaining oxyanions will degrade below pH 10 and thus release the bound oxyanions upon further carbonation.

Chromium

The mineral phases identified in the geochemical modelling match in many cases quite well with the observed leachability. Particularly, in the case of Cr a relevant solubility controlling phase has been identified that describes Cr leachability over the entire pH range from pH 4 up to about 12 and over a wide range of concentration levels. Both aspects form a strong proof that the relevant controlling phase for Cr VI has been found. The controlling phase is a solid solution of bariumsulphatechromate with different sulfate/ chromate proportions. For $Ba(S77Cr23)CrO_4$ or $Ba(S96Cr4)CrO_4$ stability constants have been published. In Figure 3.12 the modelling results are given, the consequence of this solubility control is that by raising the concentration of one component (e.g. Ba) the Cr solubility should drop

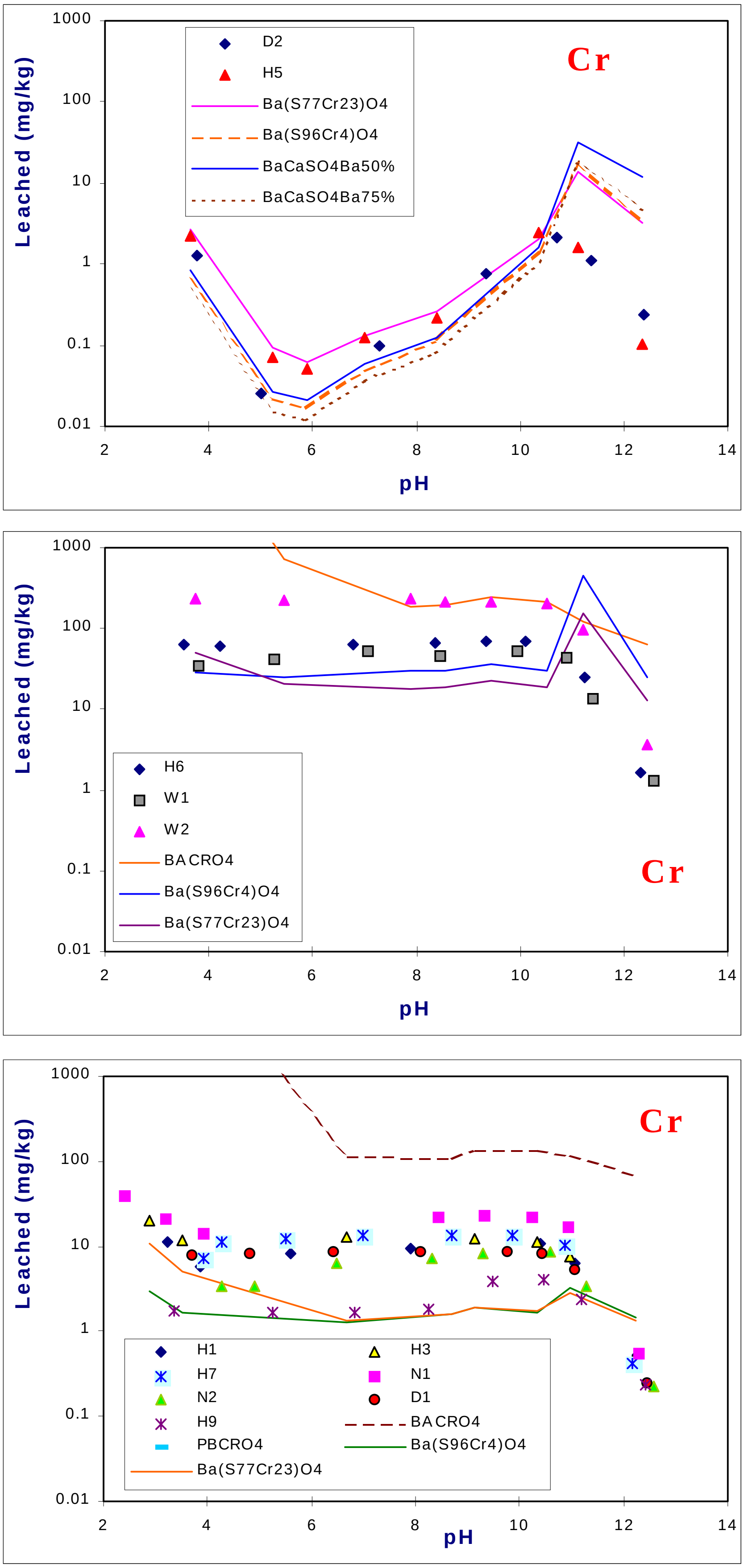


Figure 3.12 *Geochemical modelling of Cr leachability from different cements with Ba(S77Cr23)CrO4 as the most likely solubility controlling phase.*

In Figure 3.13 the modelling indicates that raising the Ba concentration 10 - fold may lead to a significant reduction in Cr leachability.

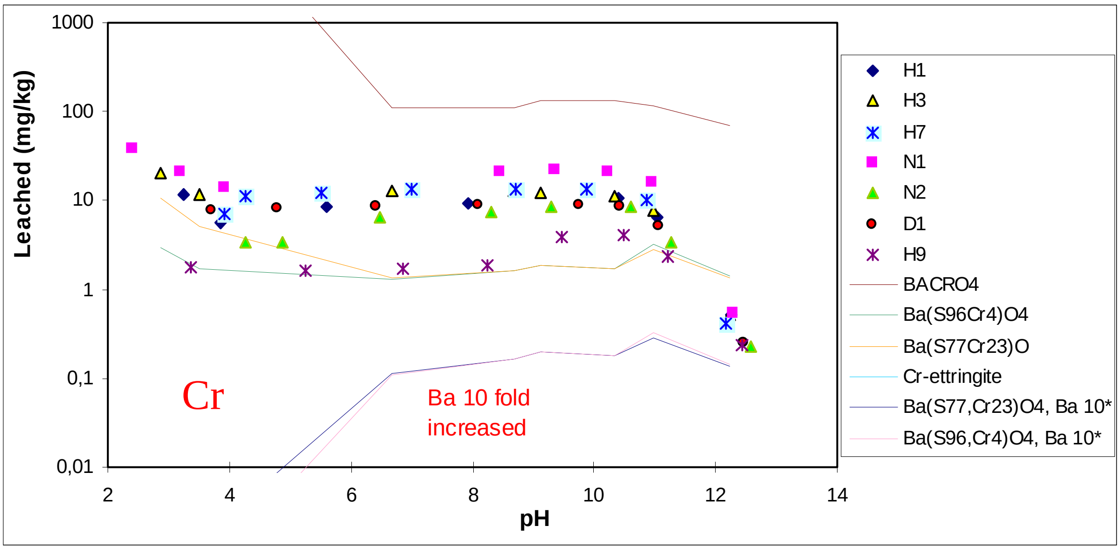


Figure 3.13 *Modelling of release for 10 fold increased Ba concentration showing strong reduction of Cr leachability*

The different behaviour of Cr leaching for two test cements is quite marked. From earlier studies [13,29] slag cements prove to have the same leaching characteristics. Clearly, of all cements the traditional Portland cements feature the highest Cr leachability. The special cements with increased Cr levels feature increased Cr leachability with a positive correlation but no proportionality between total Cr and leachability. The reason for the low Cr leachability in H5 and D2 must be found in reducing conditions in the cement during production. The distribution between CrO_4^{2-} and Cr^{3+} is causing the difference in Cr leaching behaviour between the different cements. Blast furnace slag cements feature lower Cr leachability as a consequence of reducing properties of blast furnace slag, which implies that all Cr is in the Cr^{3+} state. This is illustrated most clearly in Figure 3.14. At high pH (pH. 7) Cr III is not leachable. This implies that all leachable Cr measured at pH > 7 is present as Cr VI.

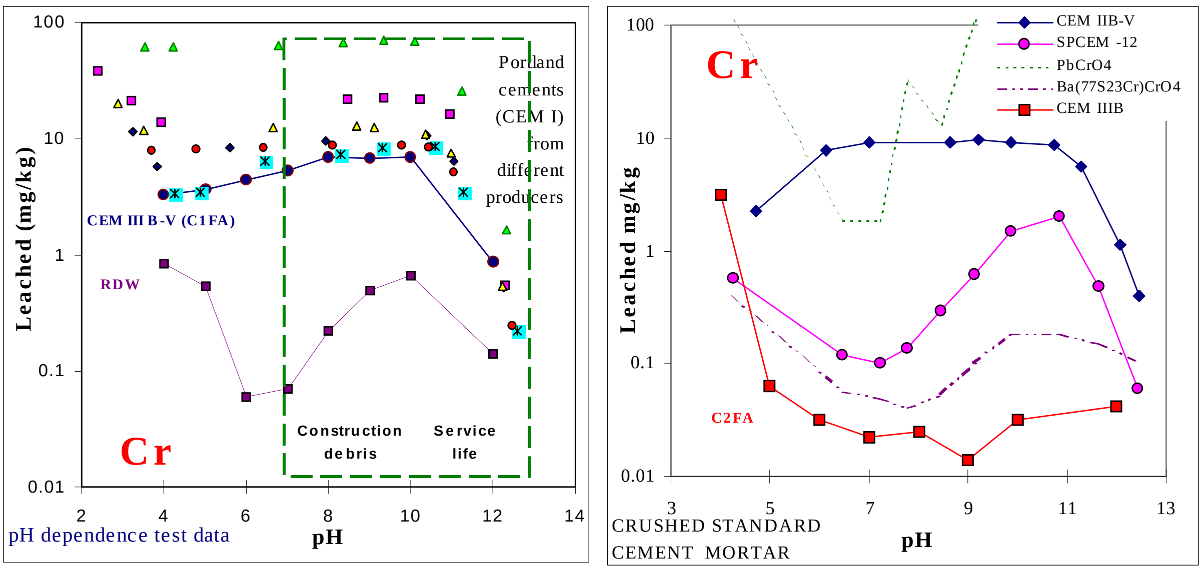


Figure 3.14 *Cr speciation in relation to leachability of different cement types (CEM IIB - fly ash cement, CEM IIIB - blast furnace slag cement, SPCEM - artificial slag cement).*

A key question in case of Cr speciation is, whether Cr VI originally present in Portland cement [38] is slowly converted to Cr III in hardened mortar/concrete, which at long term does not pose a problem, or whether Cr is released during service life and as such leads to less Cr leachability from construction debris. At present the first seems to be the most reasonable assumption. This needs to be verified in the next phase ECRICEM II.

Ferrous sulfate has been used as an additive to reduce Cr VI in Portland cements. [39]**.** This is a means of reducing Cr VI in the final product as soon as the casting takes place, as reaction only occurs in the water phase. However, it has been noted that upon storage of cement the reducing effect may be lost [40]. This may be attributed to oxidation of Fe II to Fe III by atmospheric oxygen.

Aluminium

The leachability of Al is of importance in applications of concrete or mortar in drinking water systems[41]. At high pH conditions, which may develop in case water is stagnant for relative long time, the pH-values and leaching rates of Al from cementitious materials can exceed the drinking water limits. Conditioning (i. e. artifical carbonation) is therefore required to reduce the pH-values and the leachability of Al.

The leachability of Al from crushed cement mortar as a function of pH illustrates that the leaching behaviour of Al responds very sensitively on any change in the pH conditions The Al leaching character from different types of cement is not the same (see Figure 3.15). This leaching behaviour is also reflected in the release from intact concrete specimen.

The information gained by this type of testing and modelling can hold the key to the possible cause, as relationships with chemical speciation can be made. The level of release will be determined by the pore structure of the mortars. Fortunately, leachability of Al has a minimum at around neutral pH. However, there are indications that some types of cement, particularly, fly ash cement and slag cements may show a significantly higher leachability at mild alkaline to neutral pH than regular Portland cement.It is worthwhile to verify this aspect in the next project phase.

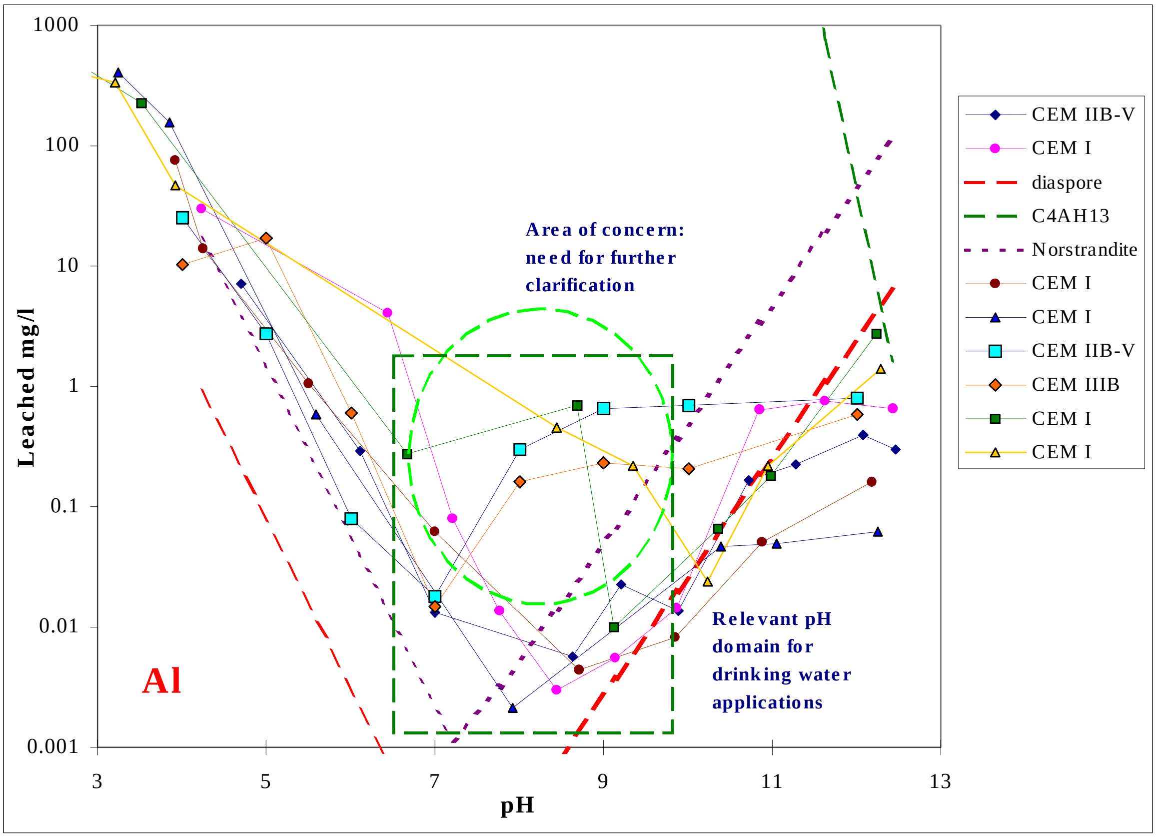


Figure 3.15 *Aluminium leachability from a variety of crushed cement mortars. Geochemical modelling of Al using MINTEQA2 is included.*

Based on the information generated within the project, the release from drinking water pipes made of a selected cement mortar can be modelled using a release model that takes parameters derived from the tank leaching test (e.g. transport parameter for each element of interest, availability) and geometrical aspects of the pipe (surface to volume ratio, S/V), the flow rate and the time of stationary conditions with and without a pre-conditioning step into account. This approach is currently worked out and will be part of the work of ECRICEM II. This then allows to vary exposure conditions, which in turn can be verified under field conditions.

By geochemical modeling a solid solution of barium sulfate/barium chromate has been identified as a controlling phase for Cr VI release.
The leaching behaviour of Al (and Cr) is different for different cement types (OPC, blended cements). Due to the importance of Al in drinking water applications, more systematic studies are needed for clarification.

3.8 Comparison of monolith tank test data (service life) with regulatory criteria

In Figure 3.16 the range of release data as provided in table 3.6 has been recalculated for selected elements using 3-D modelling of a cube of 10x10x10 cm in comparison with regulatory limit values of the Dutch Building Materials Decree [44]. Only Se appears to be critical in relation to the low limit values specified in the BMD.

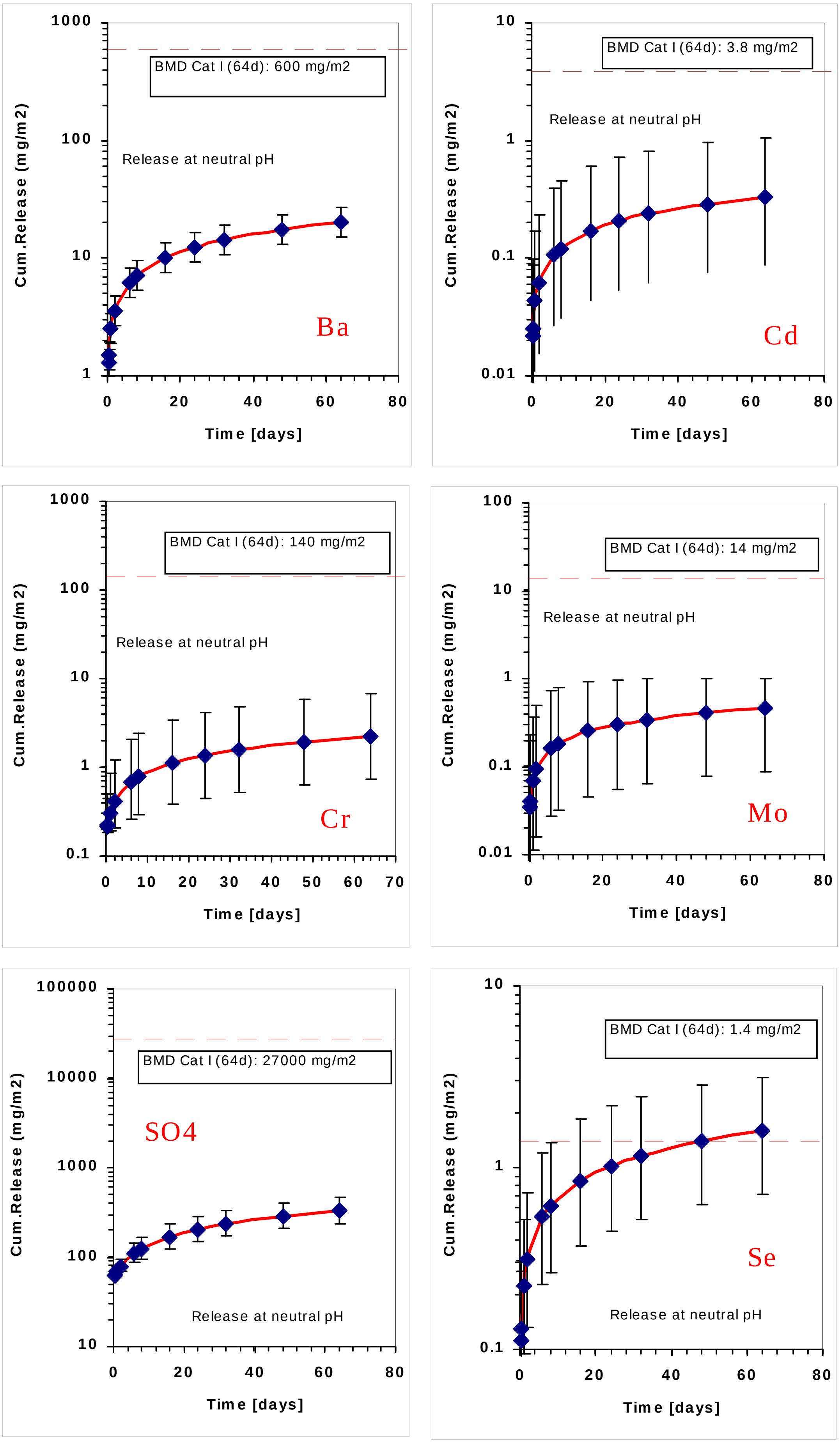


Figure 3.16 *Average release in 3D model for concrete based on all specimen tested in*

comparison with the category I criteria of the Building Material Decree at neutral pH conditions.(limit values specified in each graph for the element concerned). Maximum release derived from availability strictly applicable only for the specimen size tested (here10 cm cubes).

In the comparison with regulatory limits (only present in the Netherlands at this stage, BMD), the service life of concrete generally does not pose a problem. In the tank leach test at own pH none of the elements exceeds BMD Cat I limits. In cases of testing under imposed neutral conditions the release of Mo, Se, and Sb increases. This observation is relevant for evaluation of cement-based systems exposed to neutral environments (many cases). This response to changing exposure conditions is very much in line with pH dependence data, which endorses the use of this test for assessing alternative exposure environments.

3.9 Release Modelling

The modelling of release is based on scenario descriptions [11,43] for the various applications of cement based products [6,8,29], in which the exposure conditions of the material in the long term are identified. The results from any laboratory leaching test can not be translated in a 1: 1 relationship to the field situation. Data need to be interpreted and transferred to meet the conditions in a specific scenario. Besides, the exposure conditions change with time, which can have major effects on the release. Such changes can only be addressed by combining the information from more than one test to come to a final conclusion.

Typical primary application scenarios:

A 1. Utilisation of concrete in direct contact with drinking water (concrete pipes and basins)
A 2. Utilisation of concrete in structures exposed to fresh surface water (e.g. pilars for bridges, quays, breakwaters, locks)
A 3. Utilisation of concrete in the marine environment (breakwaters, oil rigs, embankments, etc)
A 4. Utilisation of concrete in contact with ground water (pilings, shafts, etc)
A 5. Utilisation of concrete in surface structures (all forms of building on land)

Recycling aspects(secondary application):

R 1. Recycling in of concrete construction debris in concrete as aggregate
R 2. Recycling of construction debris as unbound aggregate

End of life aspects:

L 1. Landfilling of fines from construction debris and multiple recycled material not meeting criteria for reuse.

For each of these applications the relevant boundary conditions can be identified. A first comparison with regulatory criteria for the cements tested is given in Annex 14.

A major point in this context is whether the material will remain intact, as that decides which model to apply and what test data to use. Another crucial factor is the degree of contact with water. Intermittent wetting will result in net slower release in most cases, unless the wetting results in increased degradation (water-air interface, corrosion by sea spray). The degree of contact with water will also have an influence on the exposure to atmospheric CO_2 or CO_2 derived from biological degradation. Permanent submersion will generally result in slow carbonation. Below typical exposure conditions relevant to an overall assessment are given.

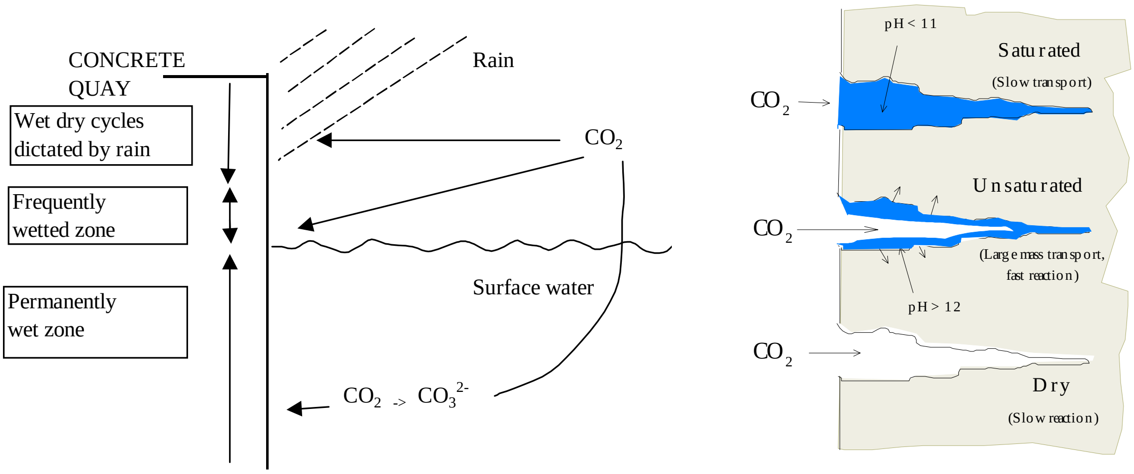


Figure 3.17 *Schematic representation of exposure of a concrete quay to weathering and a clarification of the mechanism and rate of CO_2 uptake in the paste through pores.*

In the schematic graph given in Figure 3.17 the frequently wetted zone is the zone where the most significant uptake of CO_2 will take place. The wetting of the internal pores will ensure maximum transfer of CO_2 from the atmosphere (CO_2 pump).
The boundary conditions will define when the monolith and granular leach test data need to be used. The potential for pH change will determine whether pH dependence test data are needed to translate results to other exposure conditions.
A few examples will be discussed briefly):

Permanently water exposed monolithic pillar.

For a cement-bound material with a cross section of 50 cm permanently in contact with water, where the initial pH changes in about 100 days from the own pH to the environmental pH (pH 7-8), the tank leach test data provide effective diffusion coefficients that allow a prediction of release assuming diffusion controlled release over the time frame in consideration. In Figure 3.18 the transport data for Cd are taken from table 3.6. The range of all cements is used.

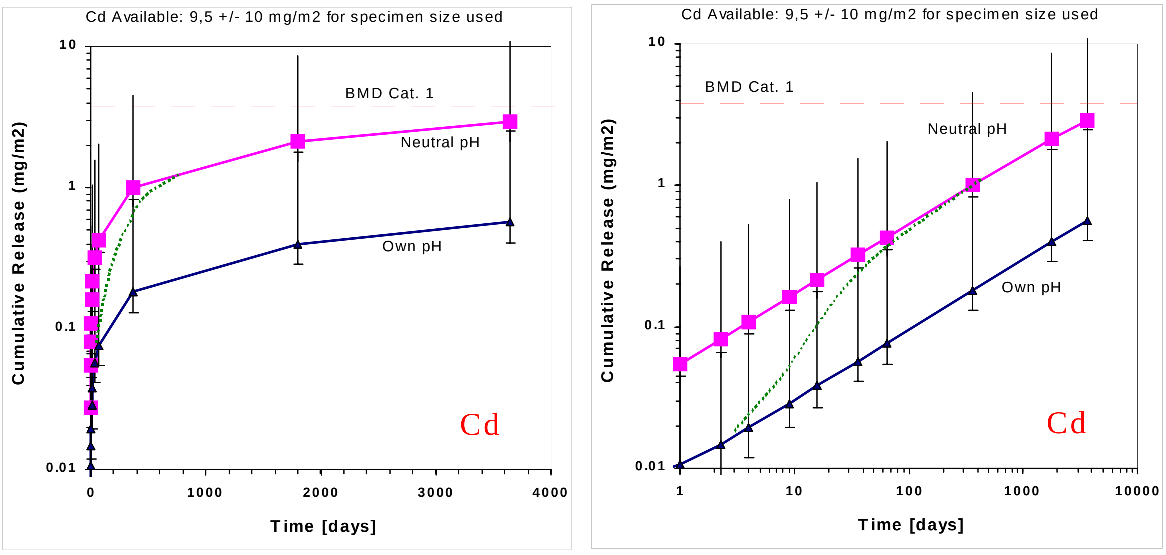


Figure 3.18 Predicted release using a 3-D diffusion model taking tank leach test data as starting point. The horizontal broken line is the category I criterion for the Building Materials Decree (BMD) [44]. The dotted line reflects the cross over from own pH to neutral pH. Left time scale linear, right logarithmic.

In comparison with the Dutch BMD, the release under own pH conditions would meet the requirements for Category I. However, the pH change with time will result in a higher release and as a consequence approach the limits more closely after about 15 years. The question arises, if the process of release will progress as projected. Since the release will be superficial and the transport within the specimen slower than in the surface, a retardation effect can be expected, which will lead to a slower release in the case of the neutral pH exposed specimen. Part of the increase projected will be reduced by this effect. Modelling the pH front (in progress) will allow to take this effect into account,

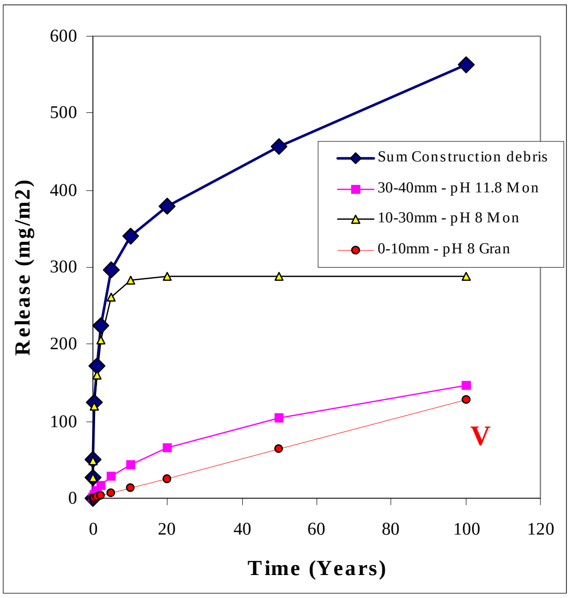
Construction debris with more or less carbonated particles of different sizes (road base applications):

The size range of construction debris can range from very coarse material (to be judged rather as monolith) to fine material, which is best judged as a granular material. Based on an assumed size fractionation in construction debris, a composite has been prepared, where the leaching contributions from the various parts is combined. The main conditions are outlined below.

Particle size (mm)	Proportion % of total (w/w)	Condition	Mode of release	Density kg/m3	Weight (kg)
30 - 40	50	pH 12	diffusion	2115	425
10 - 30	35	pH 8	diffusion	2115	297
0 - 10	15	pH 8	percolation		127
			Bulk density	1700	

The height of the road base application is assumed to be 50 cm, which results in 850 kg/m2 of soil surface.

In Figure 3.19 the data are graphically presented for the element V.



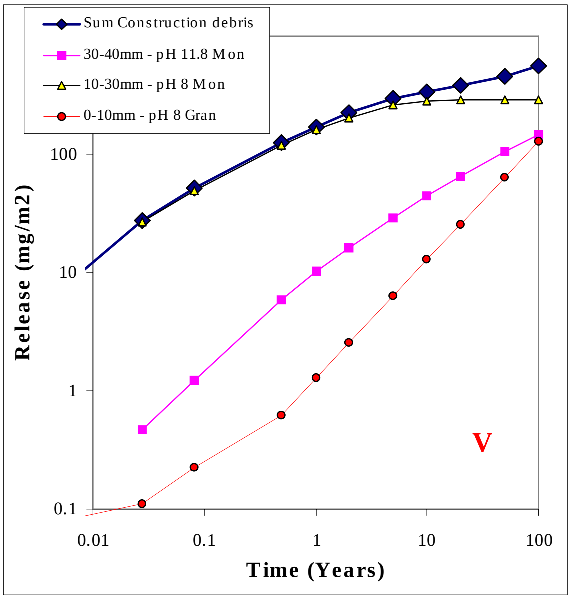


Figure 3.19 *Release of vanadium from construction debris taking into account alkalinity in larger particle sizes, neutralisation of small particle sizes and leaching from fine granular fractions by solubility control. Left time scale linear, right logarithmic.*

The basis of the approach consists of splitting the release mechanisms from the different size fractions in independent release to the liquid flowing through the material. This is of course a simplification, but it does give an impression of the major effects.

For the fine granular fraction full carbonation is assumed and release by a percolation mode. For the intermediate fraction surface neutralisation is assumed. While for the coarse fraction, the original alkaline matrix is assumed to have remained intact. The relevant release parameters have been taken from the pH dependence test data for the granular material and from table 4.1 for the monolith under own resp. pH neutral conditions.

It is clear that the particle size distribution has a major effect on the outcome. Relevant data need to be established for this to make better predictions. In this case it can be seen that apparently the fully carbonated small particles contribute most to the overall release. The modelling needs to be verified in the next phase against actual measurements of sub-fractions separated by sieving from construction debris.

> The laboratory tests to be applied depend on the exposure scenario. One test may not be sufficient.
> From an environmental point of view (different exposure scenarios), testing at neutral to mildly alkaline conditions is more relevant than testing at very high pH (pH >11).
> In any prediction of the long-term release of metals from concrete debris (reuse or landfill scenario) the effect of different particle size fractions (including carbonation) have to be taken into account.
> Transformation of $Ca(OH)_2$ to calcite (pH buffer 7.8 - 8.3) is very limited during service life. It increases significantly in a recycling stage as unbound aggregate (construction debris) and during "end of life" conditions (disposal).
> For environmental assessment of concrete in its different life cycle stages, this implies that a pH domain between pH 7.8 and 12.6 is the most appropriate. Only in rather acidic environments, the buffer may not be sufficient to maintain stable conditions over long time scales.

3.10 Relevant Data from Other Sources

3.10.1 Pb and Zn Additions

Leaching experiments with PbZn slag as aggregate in concrete, as fine ground material and straight addition of PbO and ZnO to cement paste have been carried out as a side study in relation to a study on alternative materials in pavement applications [45]. This work has resulted in levels of Pb and Zn in the concrete cubes far exceeding any of the compositions in this work. The Pb concentrations in the concrete containing Pb/Zn-slag as aggregate and concrete containing PbO/ZnO as addition to the cement paste are respectively 8750 and 9190 mg/kg. The Zn concentrations in these two materials are respectively 29800 and 22800 mg/kg.

In Figure 3.20 the pH dependence test data on size reduced cubes are shown in comparison with cements studied in this work. In the relevant pH domain pH 7 - 11 no significant change in leachability was observed with PbZn slag for Pb due to the solubility control dictated by the cement matrix. For Zn added as ZnO an increased leachability is noted. At pH > 12 both Pb and Zn increase significantly. No change is observed for Zn in the PbZn slag as aggregate

In the tank test on specimen with PbZn slag and with PbO and ZnO addition to cement, the almost 400 fold increase of the Zn and more than 500 fold increase in Pb concentration in ZnO and PbO doped mortar results in a 20-fold increase in the leachability from the tank test at own pH. For Zn in PbZn slag aggregate mortar, no increase is observed (Figure 3.21). It appears that, Zn incorporated during the clinker production (special ‘spiked’ cements) does not lead to a different leaching behaviour than direct addition of ZnO to the cement paste. If over the testing period only a limited change in pH occurs, the pH dependence test data can be used to obtain an estimate of the magnitude of change in release from the tank leach test.

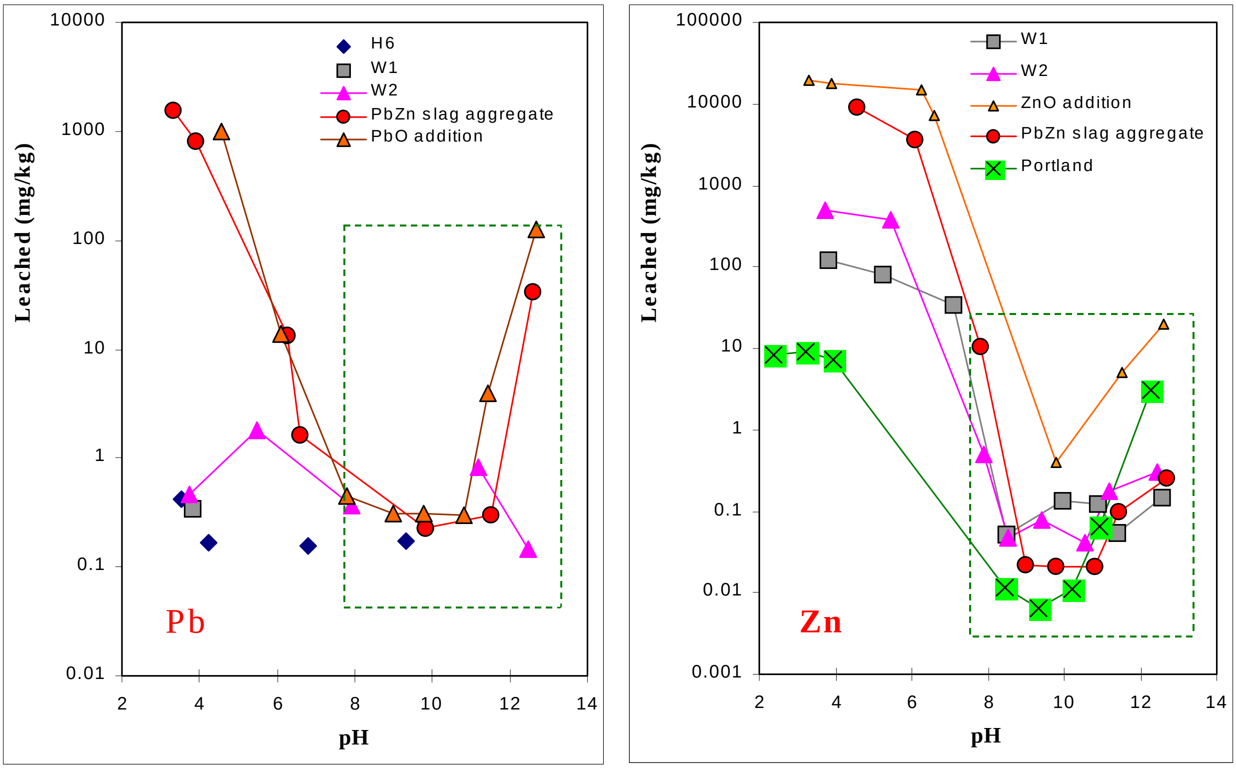


Figure 3.20 *Leaching behaviour of crushed concrete with different levels of Pb and Zn*

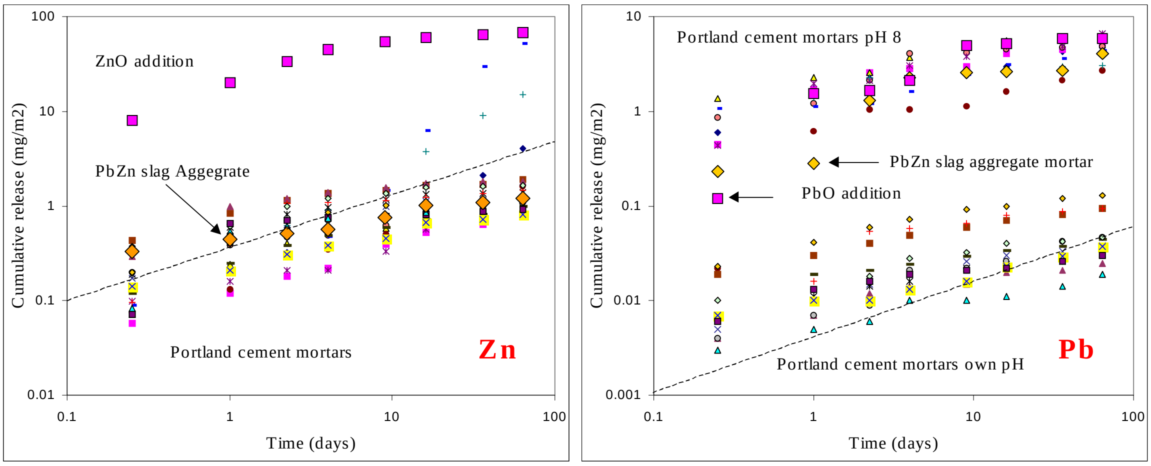


Figure 3.21 *Tank test results for Pb and Zn from PbZn slag as aggregate and Pbo and ZnO additions to the past in comparison with regular Portland cement.*

3.10.2 Comparison with Data from the Project Harmonisation of Leaching/Extraction Test

In the framework of the network Harmonisation of Leaching/extraction Test (SMT4-CT96-2066, [12]) construction products have been tested. It concerns a mortar with coal fly ash (coded C1FA; CEM IIB-V) and a mortar with blast furnace slag (BFS) cement (coded C2FA;CEM IIIB). Two additional products were tested: Drinking water pipe materials (DWP) and construction debris (RDW or C&D waste). The latter is relevant for the assessment of the long term behaviour of construction products in their recycling and 'end of life' stage. In Annex 15*(??)* the full results are gathered.

A major conclusion to be made from this comparison is that the leaching behaviour as a function of pH is very consistent (in spite of the fact that measurements were carried out in different labs). The leaching behaviour of Cr from BFS has already been addressed. In Figure 3.22 two elements are shown. Cu shows no difference between the different types of cement, drinking water pipes and construction debris. Ba shows lower leaching for construction debris. The substantially lower leachability relative to all other mortar samples may be attributed to the level of carbonation and changes in the sulfate leachability.

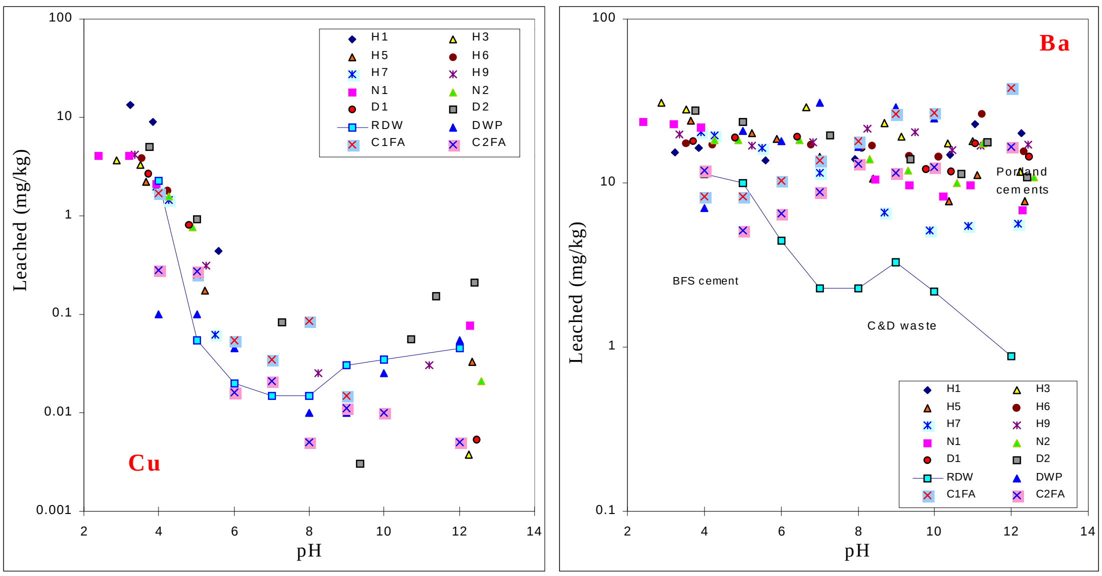


Figure 3.22 *Comparison with data from other sources. RDW is construction debris (C&D waste) and DWP is Drinking water pipe).*

The role of alternative/synthetic aggregates in the leaching behaviour of concrete can be studied in a similar manner at the work presented here [46]. This is an aspect to be addressed in more detail in ECRICEM II.

The data on concrete and mortars from other work are quite consistent with the present observations, which indicates that the leaching character of Portland cement mortars has been determined and fixed.

4. SUMMARY: EXPOSURE SCENARIOS AND CORRESPONDING TEST PROCEDURES

As a starting point for evaluation of different stages of the life cycle of cement-based products table 4.1 summarises the possible scenarios, the stage in the life cycle, the relevant characterisation test and the relevant compliance test. This evaluation needs to be worked out further in the next phase of the project. Figure 4.1 gives the same information in a more schematic fashion.

Table 4.1: Exposure Scenarios and Recommended Tests

SCENARIO	STAGE	CHARACTERISATION	COMPLIANCE
Concrete in contact with groundwater	Service life	Tank leach test (own pH)	Monolith compliance test (own pH)
Concrete in contact with surface water and constructions on land (pilars, quays, breakwaters, locks)	Service life	Tank leach test (imposed neutral pH)	Monolith compliance test (imposed neutral pH)
Concrete in contact with sea water (oil rigs, quays, breakwaters)	Service life	Tank leach test (seawater)	Monolith compliance test (seawater)
Concrete in contact with drinking water	Service life	Tank leach test (imposed neutral pH after preconditioning)	Monolith compliance test (imposed neutral ph after preconditioning)
Concrete debris recycled as aggregate	Recycling	Tank leach test (imposed neutral pH)	Monolith compliance test (imposed neutral pH)
Concrete debris reused in roadbase (unbound)	Reuse	pH dependence test on crushed material and percolation test	pH neutral imposed on crushed material
Concrete debris used in embankment and structural fill	Reuse	pH dependence test on crushed material and percolation test	pH neutral imposed on crushed material
Concrete debris in landfill	Disposal	pH dependence test on crushed material and percolation test	pH neutral imposed on crushed material

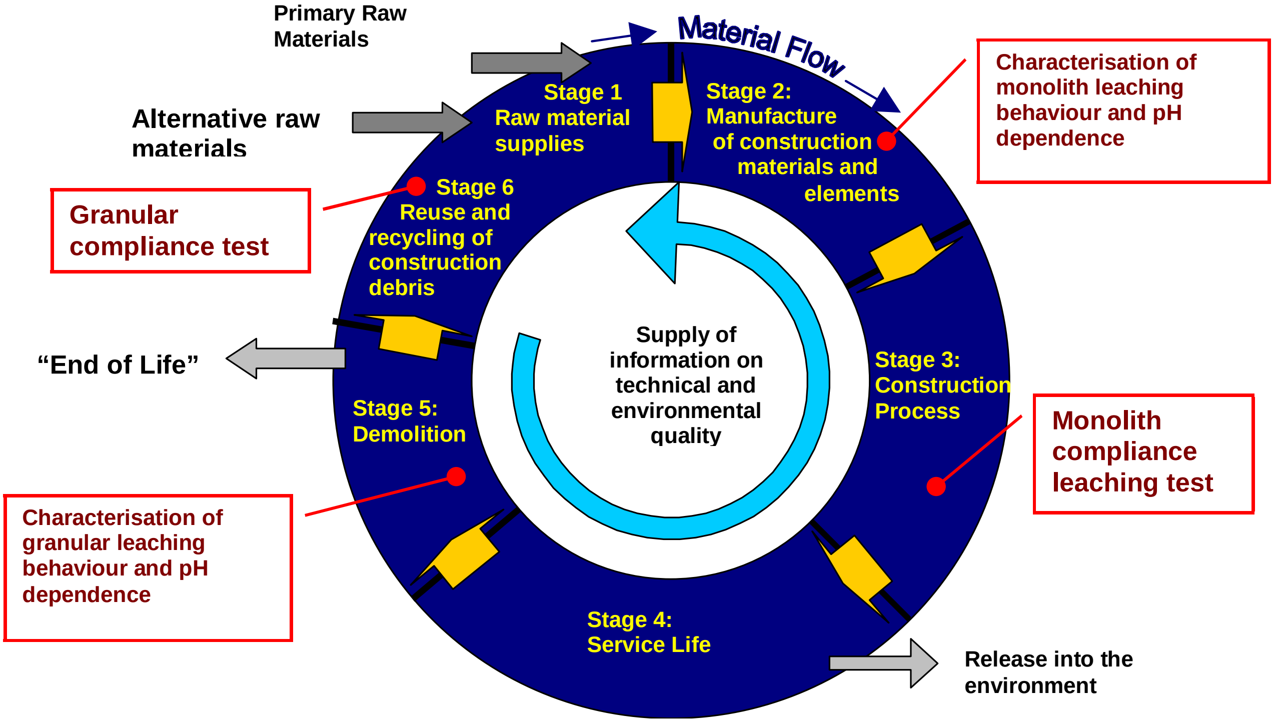


Figure 4.1 *The building cycle with associated test methods at the different levels (characterisation and compliance) for the various stages in the life cycle of cement-based building materials*

.

5. RECOMMENDATIONS FOR ECRICEM II

The following aspects will be addressed in project phase 2:

- The focus in ECRICEM phase I has been on Portland cements. In the next phase, the main emphasis shall be on blended cements. To a limited extent aggregates and concrete mix design will also be addressed.

- Development of a model scheme for the prediction of the potential short and long term release of trace elements from concrete under various exposure scenarios, based on laboratory tests and geochemical modelling.

- Verification of these (theoretical) predictions in selected field applications and studies.

- Detailed investigation into the specific leaching behaviour of chromium: a key question in case of Cr speciation is, whether Cr VI originally present in Portland cement is slowly converted to Cr III in hardened mortar/concrete, which at long term does not pose a problem, or whether Cr is released during service life and as such leads to less Cr leachability from construction debris.

- Modification of test procedures: the pH dependence tests are carried out with acid/base. In case of cement matrices, pH adjustment with CO_2 may prove more appropriate. This implies using CO_2 bubbling with control of CO_2 ratio in gasflow to reach a pre-set pH.

- To obtain porewater by compression is not very successful as only very small samples are obtained (with very limited number of analysis). An alternative approach may be based on 'down scale cascade test' – a test method in which fresh solid is added to the solution instead of fresh liquid. This allows to go in a few steps to L/S - 0.1. Another option is to carry out a percolation test and collect only the very first fractions.

- Evaluation of the ecotoxicological effects of aqueous solutions resulting from the contact of cement based products with water under different field conditions.

- Development of criteria for the acceptance of alternative fuels and raw materials in cement manufacturing, and for the assessment of the environmental impact of cement based products during their complete life cycle.

- Definition of criteria and standards for the assessment of cement based products with regard to environmentally sound recycling.

- Development of a practical environmental quality control scheme (test procedures) in the manufacture and application of cements made with or without alternative fuels and raw materials.

- In the next phase also more prominent links to CEN TC's working in the area of cement-based products shall be sought. This relates to CEN TC's 51, TC104, TC 227 and TC 164.

- A more active role of the project team in the developments around the Construction Products Directive (CPD) should be taken. The new ECO-Serve project (recently granted EU Project) will help facilitate that goal. The EU research project and Thematic Network on Harmonisation of leaching/extraction tests will provide a basis for the necessary links between other fields of leaching tests development.

6. REFERENCES

[1] Mantus, E.K., K. Kelly, G.A. Pascoe(1992): *All Fired Up – Burning hazardous waste in cement kilns* Environmental Toxicology International.

[2] Karstensen, K.H.(1994): *Burning of hazardous waste as co-fuel in a cement kiln- does it affect the environmental quality of cement?* In: Environmental Aspects of Construction with Waste Materials. Studies in Environmental Science 60. Eds. J.J.J.M. Goumans, H.A. van der Sloot, Th.G. Aalbers. Elsevier Science Publishers, Amsterdam, 1994

[3] Degre, J.P. (1996): *Waste Co-processing in Industry. Criterias for an optimal waste management in the Cement Industry*. Ditec, Obourg, November 1996 (unpublished).

[4] Sprung S. and W. Rechenberg: *Einbindung von Schwermetallen in Sekundärstoffen durch Verfestigen mit Zement. Beton*, 38, 1988 H5, 193 – 198.

[5] Rilem Workshop(1992): *Auslaugverhalten von Beton und zementgebundenem Material* 1992, Vienna

[6] Groot G.J. de, H.A van der Sloot (1990): *Determination of leaching characteristics of waste materials in relation to environmental product certification. Proc. Sec. Int. Symp. Stabilisation/solidification of Hazardous, Radioactive and Mixed wastes*. Williamsburg, Virginia, May, 29 to June 1, 1990.

[7] C.W. Versluijs, I.H. Anthonissen and E.A.Valentijn(1990):. Mammoet '85. Report 738504008. RIVM, June 1990.

[8] Sloot, H.A. van der(1995): *Environmental efficiency of immobilisation techniques for wastes in relation to utilisation and disposal*. Stabilisation Conference. Nancy, France, November 1995

[9] CEN report TC51 TC 104 (1999): *A study of the characteristic leaching behaviour of hardened concrete for use in the natural environment* N614 (in preparation).

[10] Nischer.(1992): *Leaching behaviour of concrete and cement-bonded materials. Concrete precasting plant and technology*, 12, 1992, 76 – 80

[11] Sloot, H.A. van der, L. Heasman and Ph. Quevauviller (1997): Eds.: *Harmonisation of leaching/extraction tests*, 1997b. Studies in Environmental Science, Volume 70., Elsevier Science, Amsterdam, 292 pp.

[12] EU project SMT4-CT96-2066 (2000): *Technical support to the Network Harmonisation of Leaching/Extraction tests* (2000).

[13] H.A. van der Sloot, D. Hoede (1997): *Long term leaching behaviour of cement mortars*. ECN –97-042,

[14] Construction Products Directive (CPD).89/106/EEC, 1988 and 93/68/EEC, 1993.

[15] EN – 197- (2000): *Cement: Part 1: Composition, specifications and conformity criteria for common cements*. 1 June 2000.

[16] EN196-1: *Test methods for Cement*. Part 1: Determination of strength

[17] NEN 7341 (1994): *Determination of the availability for leaching from granular and monolithic contruction materials and waste materials.*1994.

[18] NEN 7345 (1994): *Determination of leaching from monolithic construction materials and waste materials by means of a diffusion test*. October 1994.

[19] Sloot, H.A. van der, D.S. Kosson, T.T. Eighmy, R.N.J. Comans and O. Hjelmar (1994): *An approach towards international standardisation: a concise scheme for testing of granular waste leachability. In: Environmental aspects of Construction with waste materials*. Eds. J.J.J.M. Goumans, H.A. van der Sloot, Th.G. Aalbers, Elsevier Science Publishers, Amsterdam, 1994, 453-466..

[20] Kosson, D.S. and H.A. van der Sloot (1997): *Integration of Testing Protocols for Evaluation of Contaminant Release from Monolithic and Granular Wastes. In: Waste Materials In Construction - Putting Theory into Practice. Studies in Environmental Science 71.* Eds. J.J.J.M. Goumans, Senden G.J., H.A. van der Sloot: Elsevier Science Publishers, Amsterdam, 1997, 201-216.

[21] pH dependence test. CEN TC 292 (2001): *Working Group 6 Basic characterisation*. (Test in enquiry stage, 2001).

[22] Felmy, A.R., D.C Girvin,. E.A Jenne(1984):. *MINTEQA2 computer program for calculating aqueous geochemical equilibria*, EPA-600/3-84-032, U.S. Environmental Protection Agency, Athens, .

[23] Keizer, M. G. and W.H. van Riemsdijk (1998): *ECOSAT. Department of Environmental Sciences, Subdepartment Soil Science and Plant Nutrition*, Wageningen Agricultural Univ., Netherlands.

[24] Swiss Agency for the Environment, Forests and Lanscape (BUWAL) (1998): *Guidelines for the Disposal of Wastes in Cement Plants* - 1998.

[25] H.A. van der Sloot (1996): *Developments in evaluating environmental impact from utilisation of bulk inert wastes using laboratory leaching tests and field verification. Waste Management 16* (1-3), 1996, 65-81.

[26] Sloot, H.A. van der, G.J.L. van der Wegen, D. Hoede, G.J de Groot and Ph. Quevauviller(1995): *Intercomparison of leaching tests for stabilized waste*. EUR report 16133 EN, 1995.

[27] *The Rotary Cement Kiln*. 1986. 2nd ed. Chemical Publishing Co., Inc., New York.

[28] Sloot, H.A. van der (1999): *Characterisation of the leaching behaviour of concrete mortars and of cement - stabilized wastes with different waste loading for long term environmental assessment.* Waste Stabilisation & Environment, Eds J. Mehu, G. Keck, A. Navarro, Lyon, 13-16 April 1999. Proceedings 131 – 139.

[29] Sloot H.A. van der (2000): *Comparison of the characteristic leaching behaviour of cements using standard (en 196-1) cement-mortar and an assessment of their long-term environmental behaviour in construction products during service life and recycling*. Cement & Concrete Research 30, 1 – 18

[30] Glasser, F.P., D.E. Mcphee and E.E. Lachowski(1988): *Modelling approach to the prediction of equilibrium phase distribution in slag-cement blends and their solubility properties*. Mat. Res. Soc. Symp. Vol 112, 1988, 3- 12.

[31] Cougar, M.L.D., B. E. Scheetz and D.M. Roy (1996): *Ettringite and C-S-H Portland cement phases for waste ion immobilisation: a review.* Waste Management, 16 (4), 295-303, 1996.

[32] Kindness A., A. Macias and F.P. Glasser (1994): *Immobilisation of Cr in cement matrices.* Waste Management, 14 (1), 3-11, 1994.

[33] Kindness, A., E.E. Lachowski, A.K. Minocha and F.P. Glasser (1994): *Immobilisation and fixation of molybdenum VI by Portland cement.* Waste Management 14, 2, 1994, 97-102.

[34] Thesis Ivan Serclerat (1996): *Les métaux traces dans le clinker de ciment Portland: Rétention dans les mortiers et intégration dans les hydrates de ciment*. December 1996.

[35] Klemm, W.A.: *Ettringite anmdoxyanion substitutes ettringites – their characterisation and applications in the fixation of heavy metals: A synthesis of the literature*. Portland Cement Association, 1998

[36] Park, J-Y. and Batchelor, B., 2002 A multi-component numerical leach model coupled with a general chemical speciation code. Water Research, 36, 156-166.

[37] Hinsenveld, M (1991): *Towards a new approach in modelling leaching behaviour.* In: Waste materials in Construction Eds. J.J.J.M. Goumans, H.A. van der Sloot, Th.G. Aalbers, Elsevier Science Publishers, Amsterdam, 1991, 331-340.

[38] Pisters H.(1966): *Chrom im Zement und Chromatekzem*. Zement-Kalk-Gips, 19, 1966, H10, 467 – 472.

[39] Fregert, S. et al (1997): *Reduction of chromate in cement by iron sulfate*. Contact Dermatitis 1979: 5: 39-42

[40] European patents: *Chromate neutralisation by Aalborg* Portland, 0054314, 84 115 414.9, 84 115 413.1

[41] P. Leroy, S. Rigal, J. Baron, Th van den Hoven, N. Slaats, M. Morlt, C. Autugelle, I. Wagner, W. Werner, P. Oliphant, R. Conroy, R. Miller, Ph Quevauviller(2000): *Co-normative research on test methods for materials in contact with drinking water.* Final report Mat 1-CT94-0058, EUR 19602, 2000

[42] *Co-normative research on test methods for materials in contact with drinking water*. MAT1-CT94-0058. CEN/TC 164/WG3/AHG6/99-06, 1999.

[43] *Methodology Document* PrENV 12920, CEN TC 292 WG6, 1996.

[44] *Building Materials Decree*. Staatsblad van het Koninkrijk der Nederlanden, 1995, 567.

[45] *Development Of A Predictive Approach for Long Term Environmental Performance of Waste Utilisation in Pavements Using Accelerated Aging*: PCC Pavements Containing CFA. UNH, USA (In preparation). 2000.

[46] IAWG (International Ash Working Group; A.J.Chandler, T.T.Eighmy, J.Hartlen, O.Hjelmar, D.S.Kosson, S.E.Sawell, H.A.van der Sloot, J.Vehlow). (1997): *Municipal Solid Waste Incinerator Residues.* Studies in Environmental Science 67, Elsevier Science, Amsterdam, 974 pp.

[47] H.A. van der Sloot, D. Hoede and R.P.J.J. Rietra (2001): *Leaching behaviour of synthetic aggregates.* EU project BRST-CT98-5234, 2001, ECN-C-01-014.

[48] D.S. Kosson, F. Sanchez, H.A. van der Sloot (2001): *USA Paving project. Aggregate leaching behaviour*, 2001 (in preparation)

[49] H.A. van der Sloot, O. Hjemar, J. Bjerre-Hansen, P. Woitke, P. Lepom, R. Leschber, B. Bartet, N. Debrucker (2001): *Validation of CEN/TC 292 Leaching Tests and Eluate* Analysis Methods PrEN 12457 part 1- 4, ENV 13370 and ENV 12506 in Co-operation with CEN/TC 308. 2001 ECN-C-01-117.

ANNEXES

ANNEX 1 – Preparation of raw meal, operation of 150 kg/hr kiln and results.

1 Production of heavy metal doped clinkers at the pilot cement kiln

To investigate the differences between the leaching behaviour of mortars doped with soluble heavy metals and mortars produced with cements containing heavy metals, bounded to the clinker during the burning process, two clinkers with artificial high heavy metal contents were produced at a pilot cement kiln. Table 1 shows the scheduled elements and concentrations for the doping experiments, which took place on 23/24.9.1998 (clinker level 1) and 7/8.10.1998 (clinker level 2).

Table 1: Doping experiments at the pilot cement kiln

Elements	Additional concentration in the clinker level 1 (BUWAL x 2) [mg/kg]	Additional concentration in the clinker level 2 (BUWAL x 10) [mg/kg]
As	80	400
Cd	3	15
Cr	300	1500
Mo	80	400
Pb	200	1000
Sb	10	50
Zn	700	3500

For the production of the two doped clinkers 2 tons of a technical raw meal were hold available by the Research Centre of the Cement Industry (FIZ). The chemical composition (major elements) of this raw meal is listed in table 2, together with the data of a fly ash. The fly ash was used for the correction of the raw meal composition for the burning of clinker level 2 (7/8.10.1998), because the analysis of clinker level 1 produced on 23/24.9.1998 have shown a high free lime content ($CaO_{fr.}$ min. 5.43 %).

For the two experiments, each 28 kg of raw meal were mixed at the FIZ with the necessary amounts of the heavy metals (as oxides) shown in table 1. The heavy metal content of the two 28 kg mixtures (concentrates) was adjusted for a total amount of 560 kg raw meal. The two 28 kg raw meal mixtures containing the heavy metals were mixed with 532 kg of the original technical raw meal respectively with 532 kg of the corrected technical raw meal, in two steps with ratios of components of 1:4 and 1:3. To minimise the release of dust, the mixing process was done in a closed mixing drum. Table 3 shows the initial composition of the meals for the clinker production.

After the mixing process the two doped meal mixtures (each 560 kg) were granulated to pellets of 3 – 8 mm on a granulation plate with a diameter of 1 m.

Table 2: Chemical composition (major elements) of the technical raw meal and the fly ash

		Technical raw meal			Fly ash
		Cement works	Pilot kiln	FIZ	FIZ
Loss of ignition	[%]	35.80	35.31	35.23	1.95
SiO_2	[%]	13.22	13.39	13.55	42.13
Al_2O_3	[%]	3.08	3.15	3.17	25.40
Fe_2O_3	[%]	1.58	1.62	1.34	14.87
CaO	[%]	42.53	42.58	42.67	6.72
MgO	[%]	2.33	2.26	2.28	2.94
K_2O	[%]	0.79	n. b.	0.83	2.63
Na_2O	[%]	0.06	n. b.	0.10	0.66
SO_3	[%]	0.43	n. b.	0.62	1.33
Σ	[%]	99.82	98.31	99.79	98.63
KSt I		102.5	101.2	100.7	
SM		2.84	2.81	3.00	
TM		1.95	1.94	2.37	

Table 3: Initial composition of the meals for the clinker production

		Clinker level 1 (23/24.9.1998)	Clinker level 2 (7/8.10.1998)
Technical raw meal	[kg]	532	524
Fly ash	[kg]	0	8
Concentrate	[kg]	28	28
KSt I		101.4	96.2
SM		2.89	2.67
TM		2.07	2.02

The burning of the two clinkers was done at the pilot cement kiln, which is described in detail in Figure 1. Relevant process parameters for the burning of the two clinkers, as well as the free lime content (Franke) of the produced clinkers, are listed in table 4 and table 5.

Table 4: Process parameters for the burning of clinker level 1 and free lime content (Franke)

Time [h]	Raw meal Feeding [kg/h]	Natural gas [m^3/h]	Additional Oxygen [m^3/h]	Temperature (Pyrometer) [°C]	Rotation speed [min^{-1}]	$CaO_{fr.}$ [%]
0	0	5.0	0		2.0	
9.0	28.0	15.0	5.0	1226	1.55	
10.0	48.0	20.0	8.6	1350	1.55	
11.2	48.0	20.0	10.6	1360	1.55	10.35
12.0	48.0	20.0	10.6	1400	1.55	
14.0	48.0	18.0	13	1460	1.55	7.62
15.0	48.0	17.0	12.6	1460	1.55	8.02
16.0	48.0	17.0	12.6		1.55	8.63
16.3	48.0	18.0	12.2	1470	1.55	
17.0	48.0	18.0	12.2		1.55	8.46
17.7	48.0	18.0	12.2		1.08	
18.2	40.8	18.0	12.2		1.08	
18.8	30.5	18.0	12.2		1.08	
19.5	30.5	18.0	12.2		1.08	8.93
19.8	30.5	18.0	13.4	1387	1.08	
20.5	30.5	18.0	13.4	1450	1.08	
22.5	30.5	18.0	13.4		1.08	5.43
22.8	30.5	18.0	13.4	1452	1.08	
25.0	30.5	18.0	0	1471	1.08	6.02
25.4	0	18.0	0		1.08	

Figure 2 respectively Figure 3 show the amount of added raw meal, gas and oxygen, the kiln temperature, the free lime content and additional the kiln temperature measured with a thermo-couple for the burning of clinker level 1 respectively clinker level 2 in a graphic form. The fraction of the produced clinker level 1 with the lowest free lime content of 5.43 % (about 20 kg) has been used for the production of the test cement 'W1'. From the produced clinker level 2 a fraction of about 150 kg has a free lime content lower than 2 % which was used for the production of the test cement 'W2'.

Table 5: Process parameters for the burning of clinker level 2 and free lime content (Franke)

Time [h]	Raw meal Feeding [kg/h]	Natural Gas [m^3/h]	Additional Oxygen [m^3/h]	Temperature (Pyrometer) [°C]	Rotation Speed [min^{-1}]	$CaO_{fr.}$ [%]
0	0	5.0	0		2.00	
4.6	32.0	14.0	0		2.00	
6.8	32.0	17.0	9.5		2.00	
7.6	26.4	20.0	13.2	1300	1.45	
8.6	26.4	19.0	13.0		1.45	10.76
10.1	27.0	19.5	14.8	1340	1.70	6.00
11.1	33.0	19.5	15.2	1360	1.70	
11.6	33.0	19.5	15.2		1.70	5.65
12.1	33.0	20.5	15.1	1496	1.70	
12.9	33.0	20.5	13.8	1433	1.70	2.05
13.9	33.0	29.5	13.8		1.70	1.38
15.3	33.0	20.5	13.8		1.70	1.52
15.6	33.0	20.5	14.2	1430	1.70	
16.1	33.0	20.5	14.2		1.70	2.02
17.1	33.0	20.5	14.2		1.70	2.11
18.1	33.6	20.5	14.4	1480	1.44	2.02
19.1	33.6	20.5	14.4		1.44	2.05
20.1	33.6	20.5	14.4		1.36	1.74
21.1	33.6	20.5	14.4		1.36	1.12
21.6	33.6	18.0	13.8	1433	1.44	
22.1	33.6	18.0	13.8		1.44	2.20
22.6	33.6	18.0	13.5	1463	1.44	
23.1	33.6	18.0	13.5		1.36	1.94
24.1	31.8	18.0	13.7	1554	1.36	2.39
24.6	31.8	18.0	13.7		1.36	
25.1	31.8	18.0	13.7		1.36	3.25
25.6	31.8	17.5	14.1	1470	1.38	
26.1	31.8	19.0	8.0		1.38	5.15
26.6	0	10.0	0		1.38	
27.8	0	0	0		1.38	

2 Production of the test cements and test results

The two clinkers (level 1 and level 2) and for comparison the clinker made with the same raw meal at the commercial cement works (clinker D2) were grinded in a laboratory mill. After grinding the clinker powders were mixed in an Eirich mixer with $CaSO_4$ x ½ H_2O in an amount to achieve a SO_3 content of 3 % in the resulting cement. In table 6 the physical properties, setting and standard strength as well as the chemical (major elements) and mineralogical composition of the three test cements are listed. The content of minor elements of the three test cements is listed in table 7.

Table 6: Physical properties, setting and standard strength (DIN EN 196) and chemical (major elements) and mineralogical composition of the three test cements

		Cement D2	Cement W1	Cement W2
Density	[g/cm^3]	3.15	3.16	3.17
Spec. surface (Blaine)	[cm^2/g]	3605	4440	3760
Le Chatelier	[mm]	-	2.0	1.0
Water demand	[%]	24.0	28.5	23.0
Setting start	[min]	80	45	95
2d cement strength	[N/mm^2]	27.5	24.9	19.8
7d cement strength	[N/mm^2]	38.6	35.8	34.9
28d cement strength	[N/mm^2]	45.2	51.7	53.6
Loss of ignition	[%]	0.65	1.07	0.78
SiO_2	[%]	20.20	20.29	20.53
Al_2O_3	[%]	4.60	4.71	5.23
Fe_2O_3	[%]	2.26	2.11	2.38
CaO	[%]	63.94	64.97	64.03
MgO	[%]	3.42	3.35	3.34
K_2O	[%]	1.36	0.12	0.13
Na_2O	[%]	0.16	0.10	0.17
SO_3	[%]	3.08	2.97	3.07
Mn_2O_3	[%]	0.03	0.03	0.04
TiO_2	[%]	0.25	0.23	0.24
P_2O_5	[%]	0.05	0.05	0.06

Table 7: Chemical composition (minor elements) of the three test cements

Elements		Cement D2	Cement W1*	Cement W2*
As	[ppm]	6.89	102.2 (80)	337.7 (400)
Be	[ppm]	0.53	0.84	0.94
Cd	[ppm]	< 0.10	0.32 (3)	1.21 (15)
Co	[ppm]	7.47	6.51	14.39
Cr	[ppm]	28.92	335.3 (300)	1396 (1500)
Cu	[ppm]	28.95	23.39	21.94
Hg	[ppm]	< 0.02	0.03	0.08
Mn	[ppm]	217.9	200.1	229.0
Mo	[ppm]	1.08	45.78(80)	201.5 (400)
Ni	[ppm]	14.25	13.76	41.92
Pb	[ppm]	15.29	49.67 (200)	12.95 (1000)
Sb	[ppm]	3.58	7.76 (10)	30.82 (50)
Sn	[ppm]	4.81	< 1.00	3.36
Tl	[ppm]	< 1.00	0.26	0.46
V	[ppm]	21.94	24.45	27.13
Zn	[ppm]	129.7	501.7 (700)	2027 (3500)

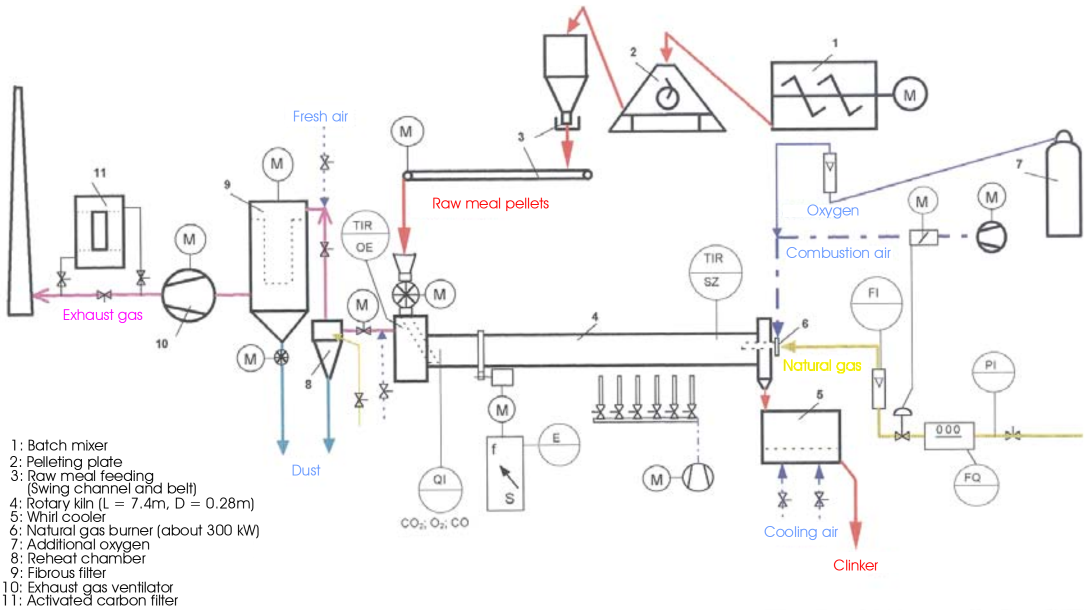
*Values in brackets are the scheduled concentrations for the doping experiments

As, Cd, Cr, Mo, Pb, Sb and Zn were artificially ‘spiked’ to the raw meal of the clinker produced at the pilot test facility.

The analytical results (Table 3.1) demonstrate that As and Cr were nearly totally incorporated in the clinker, whereas only about 50 to 80 % of added Mo, Sb and Zn was retained in the clinker structure. Most of the Cd and Pb spiked to the raw meal was lost under the specific process conditions prevailing in the small test facility.

The behaviour of these elements in the test kiln is in contrast to their behaviour in a full scale commercial kiln. In a commercial kiln, these trace elements are almost completely (clos to 100 %) bound to the solids produced – either clinker or kiln dust – due to the excellent retention capacity of a modern preheater kiln system.

Under the specific process conditions of the small test kiln – with limited contact of solids and gas due to the pelletised raw feed, the short residence time, and the lack of a preheater- a lager portion of the spiked elements – especially the ones with higher volatility (Cd and Pb)- left the kiln with the exhaust gases and were finally deposited on the filter system (textile filter ana activated carbon filter.

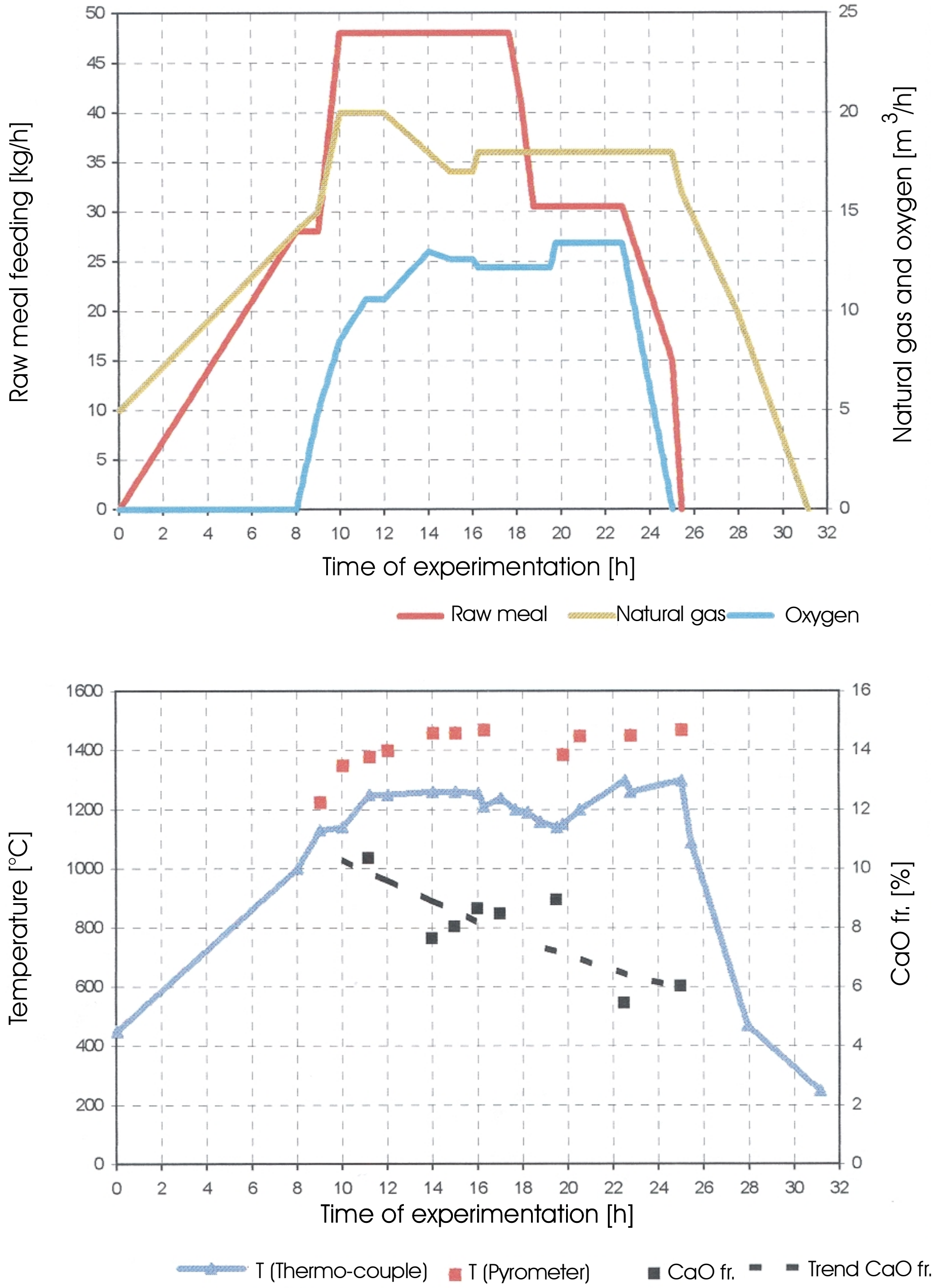


IBU-tec

Figure 1: Technological scheme of the pilot cement kiln (Weimar - Ehringsdorf)

Rotary kiln (0.3 x 7.4m^2)

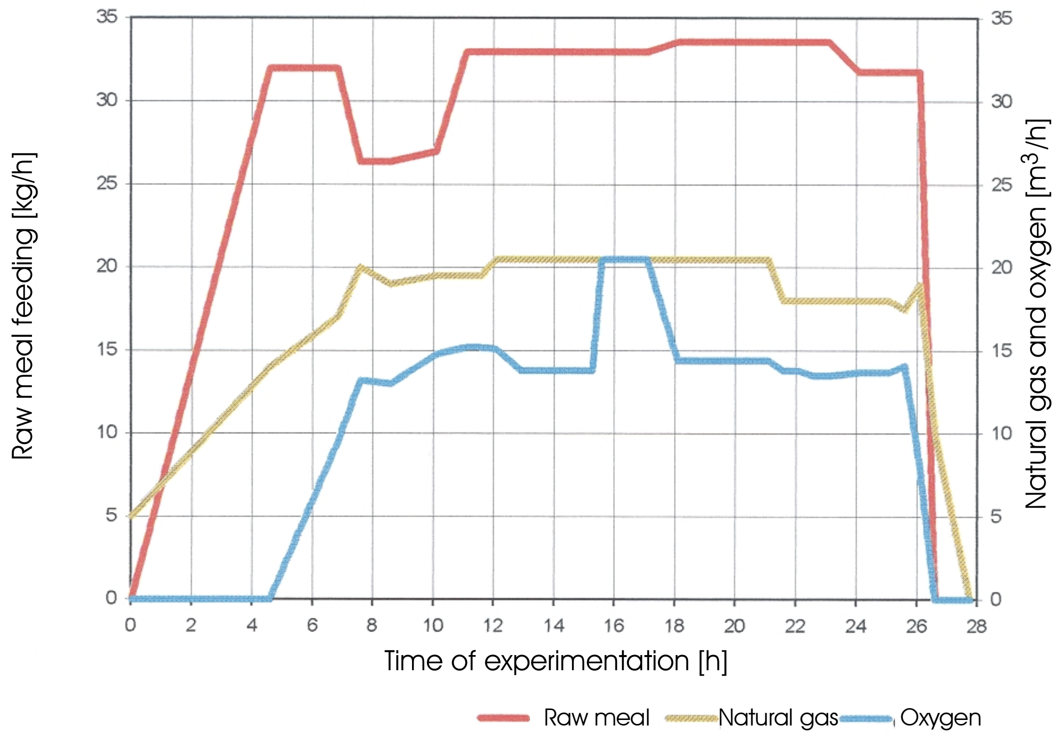
schl
10 / 98

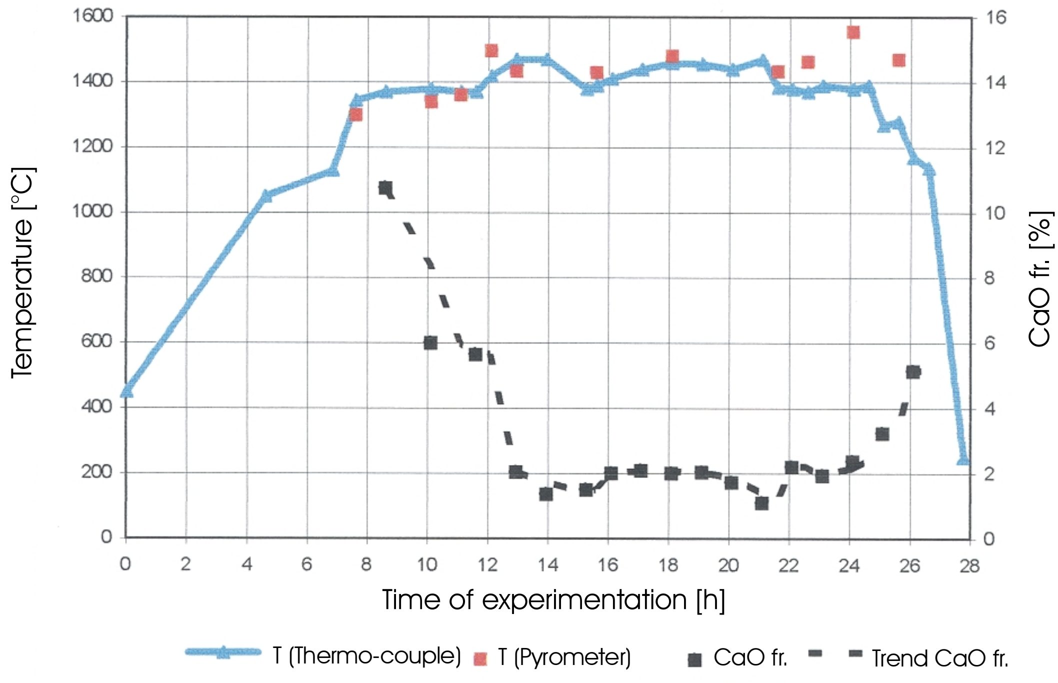


IBU-tec

Figure 2: Experiment 1, clinker level 1
Process parameters and free lime content of the clinker

schl/ki
10 / 98





IBU-tec

Figure 3: Experiment 2, clinker level 2
Process parameters and free lime content of the clinker

schl/ki
10 / 98

ANNEX 2 PHYSICAL AND OPTICAL DATA

NORCEM A.S
Dept. R&D

P.O.box 38
N-3991 BREVIK
Norway

Tel. : +47 35 57 20 00
Fax : +47 35 57 04 00
E-Mail : sigrun.bremseth@norcem.scancem.com

REPORT NO.	PROSJEKT NO	CLASSIFICATION
9D4/R99016	P 620	

TITLE OF REPORT	
MICROSCOPE ANALYSES OF MORTAR SAMPLES ECRICEM.	DATE 15.03.99
	NO OF PAGE / ENCL. 11/ 18
	AUTHOR S. Kjær Bremseth
	SUPERVISOR T.F.Rønning
CLIENT Erik Stoltenberg-Hansson	KEY WORD

ABSTRACT

In connection with the project ECRICEM, 12 bars of mortar have been investigated by means of scanning electron microscope and optical microscope. The content of the air voids and the water/cement-ratio were of particularly interest. In the leaching test it is of interest to know the quality and condition of the mortars before the mortars are exposed.

The microscopic investigation of the samples shows:

- H1 has the densest paste of cement.
- H5 has the most porous paste of cement.
- H1 has the highest content of total air voids and air voids <0,25 mm.
- N1 and H6 have the lowest content of total air voids.
- N2 has fewest air voids < 0,25 mm.
- W1 has the highest content of airvoids > 0,25 mm

In most of the samples the aggregates are mostly of fine- or coarser sand of quartz or plagioclase and are even distributed. The air voids are even distributed in most of the samples, except from H5 and N2. The paste of the cement samples are mostly homogeneous or just a little inhomogeneous. The finenesses of the the different cements were varying. The fineness of the cement and the age of the sample are factors influencing the porosity.

TABLE OF CONTENTS

ENCLOSURE

1.0 INTRODUCTION

In connection with the project ECRICEM, 12 bars of mortar have been investigated by means of scanning electron microscope and optical microscope. The content of the air voids and the water/cement-ratio were of particularly interest. It is of interest to know the quality and condition of the mortars before the mortars are exposed in the leaching test.

2.0 SAMPLES AND METHODS

2.1 Samples

Norcem R&D has received 2 x twelve samples of mortar, size 40x40x160 mm^3. A specimen is cut off from one of the bars to a size about 40x40x60 mm^3. From this specimen a 10 mm thick sample is cut from the middle of each of the original prism as in figure no.1. The thin section has a size of about 20x40 mm^2.
Another sample with a size of 20x20 mm^2 has been cut from each of the mortar for the analyses with scanning electron microscope.

Fig.1

The samples are marked as this:

Code	The date for moulding	The date Norcem received the sample
H1	**26.10.98**	**18.11.98**
N1	**02.11.98**	’’
H3	**03.11.98**	’’
D1	**04.11.98**	’’
H5	**11.11.98**	’’
H6	**12.11.98**	’’
H7	**16.11.98**	**14.12.98**
N2	**17.11.98**	’’
W1	**16.12.98**	**11.01.99**
D2	**15.12.98**	’’
W2	**17.12.98**	’’
H9	**03.02.99**	**19.02.99**

2.2 Thin section

The thin section analyses is a method to estimate the structure of the concrete with very thin section in an optical microscope.
The cut samples are ground plane at one side, dried at 30°C and evacuated in about 0,25 mbar. The sample is impregnated in fluorescence epoxy and polished. A glass-slide is glued on the polished surface. The sample is cut in about 0,5 mm thickness and ground down to a thin section with a thickness of 0,025 mm. The thin section is sprayed with a laquer and investigated in a polarization microscope.

2.3 Capillar porosity

The capillar porosity of the cement is measured with a spotlight-meter in the optical microscope. The transmission of the fluorescence light is measured in several points (40-45 points). The transmission of the air voids is used as ”zero”. The intensity of the fluorescence light from the impregnated paste of cement is about proporsonal with the water/cement-ratio.
The degree of hydration and amount of filler (for example silica) influence the porosity of the cement. The result from the spotlight-measuring is compared with measuring of a cement with known water/cement-ratio and degree of hydration. The reference sample is a mortar with CEM I 42,5 R cement (Norcem Industrisement), stored in water for 4 weeks and is 2 year old.

2.4 Quantitative analyses of the air voids and composition of the samples

The amount of aggregates , paste and air voids is determined with help of a point counter with a distance between the points of 0,167 mm and an even distribution of 2000 points in each thin section. The air voids are quantified with different size of diameter: < 0,12 mm, [0,12-0,25 mm], [0,25-1,35 mm] and > 1,35 mm.

2.5 Investigation of the sample with scanning electron microscope

The small sample (20x20 mm2) is embedded in epoxy, cut, ground and polished. The sample is covered with a thin layer of gold (Au).With help from a backscatter detector a picture of the different phases can be seen: The air voids are black, the aggregates are dark grey, the cement paste is grey with some structure. The unhydrated cement particles are light grey. The photos have a magnification of 25, 250 and 500X.

In the first step we investigated only two samples: H1 and N1. The photos told little that is not seen in the optical microscope and gave little additional information for these samples. We decided to drop this analyses for the rest of the samples.

3.0 RESULT

3.1 Thin section analyses

Table no. 1.

Sample no.	**H1** 26.10.98	**N1** 02.11.98	**H3** 03.11.98	**D1** 04.11.98	**H5** 11.11.98	**H6** 12.11.98
Cement paste	Little inhomogeneous with porous area around air voids. A lot of $Ca(OH)_2$ in the paste. Quite good hydrated.	Little inhomogeneous with porous area around air voids and some sand part. A lot of $Ca(OH)_2$.	Porous and a little inhomogeneous around some air voids. A lot of $Ca(OH)_2$.	Denser than H3, but still porous, particular near some sand part. and air voids. A lot of $Ca(OH)_2$.	Porous and homogeneous. A lot of $Ca(OH)_2$.	Denser than H5, but with some inhomogeneous area: porous near air voids and sand part. A lot of $Ca(OH)_2$.
Air voids	A lot of rounded air voids, coarse and fine. A nest of air void in a couple of area. One filled air void and several with a rim of $Ca(OH)_2$-crystals.	Few and rounded air voids. Some small, irregular air voids near sand part. In the middle of the thin section. Rim of $Ca(OH)_2$ can be seen.	Few and rounded. Mostly coarser than 0,25 mm.	Rounded air voids. Some small, irregular air voids are seen.	Rounded and a lot of coarse air voids. Uneven distribution. A nest of coarse air voids is seen.	Few, even distributed air voids. Some irregular near outer zone and near sand part.
Cracks	Few crack in the paste. Just some fine microcracks from the edge of and between aggregate or air voids.	Few crack in the paste. Some fine microcracks from the edge of and between aggregate or air voids	Some fine cracks in the paste, out from the edge of sand part. and air voids.	Some fine cracks in the paste, out from the edge of sand part. and air voids.	Few cracks, only a very few fine cracks i the paste.	A number of fine cracks in the paste out from the edge of sand part. and air voids.
Aggregates	Mostly of fine- and coarser crystalline form of quartz and plagioclase, one muscovite is seen. Even distribution of fine and coarser particles of sand. Mostly rounded, but some more edged. Mostly without cracks, only a few with some fine cracks and porous.	Mostly of fine- and coarser crystalline form of quartz and plagioclase. Even distribution of fine and coarser particles of sand. Mostly rounded, but some more edged. Mostly without cracks, only a few with some fine cracks and porous.	Mostly fine- and coarse crystalline form of quartz, plagioclase,. A few part. of sandstone, limestone and hornblende. A part. of muscovite are seen. Evenly distributed, mostly rounded and some edged, some with fine cracks. Sandstone can be porous.	Mostly fine- and coarse crystalline form of quartz, plagioclase. A few part. of sandstone, hornblende and muscovite is seen. Evenly distributed, mostly rounded and some edged, some with fine cracks. Part. with iron is porous.	Mostly fine- and coarse crystalline form of quartz, plagioclase. A few part. of sandstone and hornblende. Sandstone part. are often porous. Evenly distributed, mostly rounded and some edged, some with fine cracks.	As the others.
Water/cement ratio (measured)	0,42	0,49	0,61	0,56	0,71	0,56
Sundry	Few unhydrated particles of cement.	The cement has more coarser cement particles and has more unhydrated cement part. than H1.	Some unhydrated particles of cement.	Some gel of silica. Carbonated outer zone.	Carbonated outer zone.	Some unhydrated cement particles. Carbonated outer zone.

Table no. 2.

Sample no.	**H7** 16.11.98	**N2** 17.11.98	**W1** 16.12.98	**D2** 15.12.98	**W2** 17.12.98	**H9** 03.02.99
Cement paste	Porous and homogeneous. A lot of $Ca(OH)_2$.	Porous and homogeneous.More porously near some sand part. and in an area 10 mm from outer zone. A lot of $Ca(OH)_2$.	Porous and a little inhomogeneous with some denser area scattered in the paste. A lot of $Ca(OH)_2$.	Porous and inhomogeneous. A lot of $Ca(OH)_2$.	Porous and a little inhomogeneous. A lot of $Ca(OH)_2$.	A little denser than most of the samples, homogeneous. A lot of $Ca(OH)_2$.
Air voids	Rounded and even distributed. Some coarse, irregular air voids. Nest of some coarse air voids is seen.	Uneven distribution and rounded. Nest near porous sand part. Mostly coarser than 0,25 mm. Rim of $Ca(OH)_2$ in an air void.	A number of rounded air voids. Mostly coarser than 0,25 mm. Some irregular, small air voids are seen near edge of sample.	A lot of rounded air voids. Mostly coarser than 0,25 mm. A number of irregular air voids are seen. Collection of air voids are seen.	A number of rounded and irregular air voids, small and coarse. Evenly distributed.	A number of roud air voids, mostly coarse and evenly distributed. A number of small irregular air voids are seen.
Cracks	Some fine cracks in the paste and in som unhydrated part. of cement.	Some fine cracks in the paste, out from the edge of sand part.	Some fine cracks in the paste.	Some fine cracks in the paste, out from the edge and along the edge of sand part. A number of fine cracks in some coarse sand part.	Some fine cracks in the paste.	Some fine cracks in the paste, out from the edge of some aggregates or air voids.
Aggregates	As the others.	As the others.	As the others.	As the others.	As the others.	As the others
Water/cement ratio (measured)	0,58	0,56	0,64	0,58	0,62	0,53
Sundry	A number of unhydrated cement particles and a number of coarse particles of belite/ alite. Gel of silica is seen.	A lot of unhydrated cement particles. Outer zone is a little carbonated.	A number of unhydrated cement particles. Some dark coloured particles are seen. Outer zone is a little carbonated.	Carbonated more than the other samples (2,7 mm from the outer edge). Coarse particles of cement (alite/belite) are seen. Some gel of silica, and a number of unhydrated cement part.	Carbonated in the outer zone. Coarse particles and cement (belite) are seen. A number of unhydrated cement part. and gel of silica.	Carbonated in the outer zone. Looks good hydrated with few coarse unhydrated particles of cement, often belites. Only some partly hydrated part. are seen. Fine ground cement? (Some porous, small part. are seen. Si-filler?)

3.2 Quantitative analyses of the samples, air voids and composition.

Table no.3.

Sample	**H1**	**N1**	**H3**	**D1**	**H5**	**H6**	**H7**	**N2**	**W1**	**D2**	**W2**	**H9**
% Cement paste (P)	36,4	42,4	40,45	38,7	41,1	41,7	38,45	44,2	43,65	40,75	40,35	42,75
% Aggregates	56,2	54,3	55,1	56,55	53,7	54,75	57,2	51,35	49,8	54,4	55,2	51,05
% Air voids, <0,12 mm	1,9	0,3	0,1	0,45	0,1	0,25	0,25	0,2	0,3	0,35	0,35	0,45
% Air void, [0,12-0,25 mm]	1,3	0,2	0,65	0,7	0,3	0,55	0,3	0,1	0,2	0,05	0,3	0,15
% Air voids, [0,25-1,35 mm]	4,3	1,5	2,75	2,95	2,7	1,2	2,55	1,95	2,95	1,8	1,2	2,9
% Air voids, >1,35 mm	0	1,4	0,95	0,7	2,1	1,55	1,25	2,15	3,1	2,65	2,6	2,7
% Total air voids (A)	7,5	3,4	4,45	4,8	5,2	3,55	4,35	4,4	6,55	4,85	4,45	6,2
% A (tot)/ P	20,6	8,0	11,0	12,4	12,65	8,51	11,31	9,95	15,01	11,9	11,03	14,5
% Air voids <0,25 mm	3,2	0,5	0,75	1,15	0,4	0,8	0,55	0,3	0,5	0,4	0,65	0,6
% A(<0,25)/P	8,8	1,2	1,85	2,97	0,97	1,92	1,43	0,68	1,15	0,98	1,61	1,4

3.3 Investigation of the samples with scanning electron microscope.

In the first step of the electron microscope investigation we analysed only two samples: H1 and N1. The photos can be seen in encl. 4-7. The photos taken with a backscatter electron detector show that H1 and N1 are quite like. H1 doesn't seem to be more hydrated than N1. Only one of the area in the photos of N1 shows a more porous paste than H1. The specimen is smaller than the thin section and the preparation is not good enough for looking at porosity. It should have told us more about the rim of hydration and the amount of unhydrated particles, but doesn't give a convincing picture.

4.0 DISCUSSION

The microscope investigation shows that the twelve samples have similarities, but also some differences.
The paste of cement varies from quite homogeneous to a little inhomogeneous, often in connection with air voids and aggregates (sand particles). The porous paste around the air voids and the aggregates are caused by moisture in the porous aggregates and waterfilled air voids.
The measurement of the ratio water/cement tells something about the porosity at that moment and the grade of hydration. H5 has the most porous paste of the cement. H1 and N1 have the densest paste.
The samples are of different age, but still quite young. The reference sample is 2 year old. This can cause some of the difference in the measured w/c. The difference in age will influence the porosity of the sample and might be important for the result of the test. The samples should have been of the same age when starting the preparation of the thin sections.

Other important factors influencing the porosity are the fineness of the cement and how the samples have been stored before and after Norcem R&D received the samples.
Some of the sample have a number of coarser unhydrated particles of cement (N1, H7, D2 and W2). This will of course influence the capillar porosity of the paste.
H1 and H9 have few unhydrated particles of cement. All the other samples have some unhydrated and some partly hydrated particles of cement. Unhydrated particles are quite normal and are seen even in quite old concrete.

The outer edge of the samples show signs of carbonation. This is not unsual when a sample is exposed to the air. D2 is more carbonated than the other samples. This is impossible to explain without knowing more about the environment during the hydration.

The amout of cracks is mostly quite few in most of the samples. Only H6 has more fine cracks than the other samples. These fine cracks are caused by the variation of temperature and the volume differences during the hydration of the paste of the cement.
H7 has also some cracks in some unhydrated particles of cement. This is often seen in samples with high w/c-ratio. In this case it might be the storing and preparation that has been the cause.
The aggregates consist mainly of fine- or coarser crystalline sand of quartz or plagioclase and are evenly distributed and mostly in good condition. Only some of the particles of the sand show some fine cracks. The particles of sandstone and particles with iron are very often porous. W1 has some dark, small particles. They might be fine sand particles containing iron or coarse particles of cement with high content of ferrite.

Table 3 shows the distribution of the air voids in the samples. H1 has the highest content of total air voids and the highest content of smaller air voids (<0,25 mm).
N1 and H6 has fewest total air voids. N2 has fewest fine air voids (<0,25 mm). W1 has the highest content of air voids (>0,25 mm). The difference in the air voids structure might influence the behaviour in the leaching test.

The air voids are in most of the sample evenly distributed. Only in H5 and N2 there is an uneven distribution of the air voids.

Some small and some coarser irregular air voids are seen in a number of the samples (N1, D1, H6, H7, W1, D2, W2 and H9). This is due to natural air getting into the mortar during the casting and unproper compaction of the mortar.

In the first step of the electron microscope investigation we analysed only two samples: H1 and N1. The photos taken with a backscatter electron detector show that H1 and N1 are quite alike. H1 doesn’t seem to be more hydrated than N1. The photos told too little and therefore we decided to drop these analyses for the rest of the samples.

5.0 CONCLUSION

The microscopic investigation of the samples shows:

- H1 has the densest paste of cement.
- H5 has the most porous paste of cement.
- H1 has highest content of total air voids and air voids <0,25 mm.
- N1 and H6 (Hirocem) have lowest content of total air voids.
- N2 has fewest air voids < 0,25 mm.
- W1 has highest content of air voids > 0,25 mm

The aggregates in the samples consist mostly of fine- or coarser sand of quartz or plagioclase and are evenly distributed. The air voids are even distributed in most of the samples, except from H5 and N2 . The paste of the cement samples are mostly homogeneous or just a little inhomogeneous. The finenesses of the the different cement were varying. The fineness of the cement and the age of the sample are important factors influencing the porosity.

Enclosure 1

Explanation of the photos of the thin section.

The green/yellow photos are taken with fluorescence light and show:

- The air voids are yellow, rounded area.
- Thin lines are cracks.
- The aggregates are dark area.
- The paste of cement is green/yellow area. The darkness of the colour is an expression of the capillar porosity. Darker green/yellow colour mean less porous and denser paste.

The grey/brown photos are taken in polarized light and show:

- The air voids are yellow, rouded area.
- The aggregates are white, grey or light brown area.
- The paste of cement is dark area.

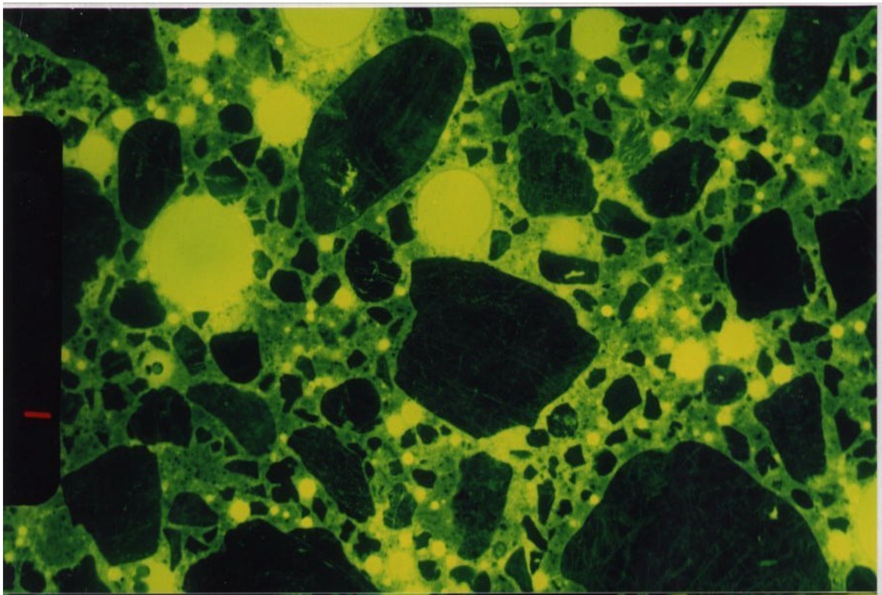
The multi coloured photos are taken in polarized light with crossed nicols and a filter of gypsum.

- The air voids are read.
- The paste of cement is dark coloured, brown/violett colour.
- The aggregates are multi coloured, singel or a number of colours.
- The carbonated area are light brown to yellow/brown.
- $Ca(OH)_2$ are yellow or turquoise small area in the paste.
- The gel of silica or alkalisilica are dark pink.

….. *The colours of the photos should not be compared because of automatic production of the photos.*

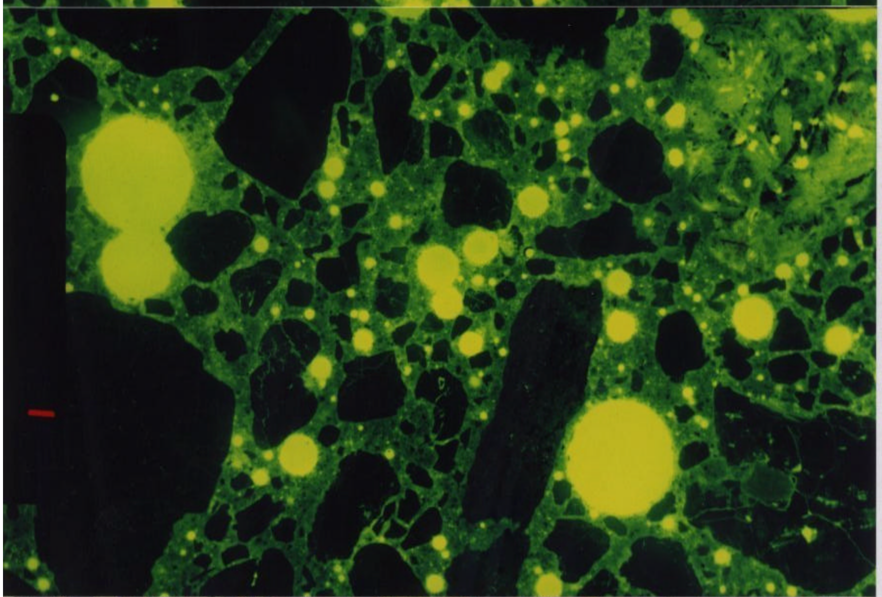
Encl. 2

H1

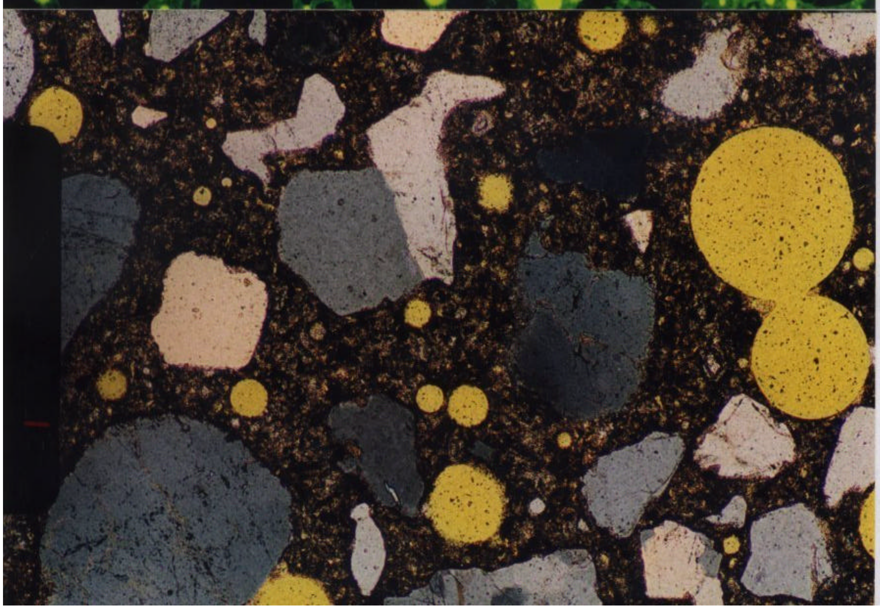


Area in the edge of the bars. Inhomogenious paste and rounded air voids.
The dark particles are sand.
Magnification: 25X.

1mm



Area in the middle of the thin section. Homogenious paste and rounded air voids.
Magnification: 25X.



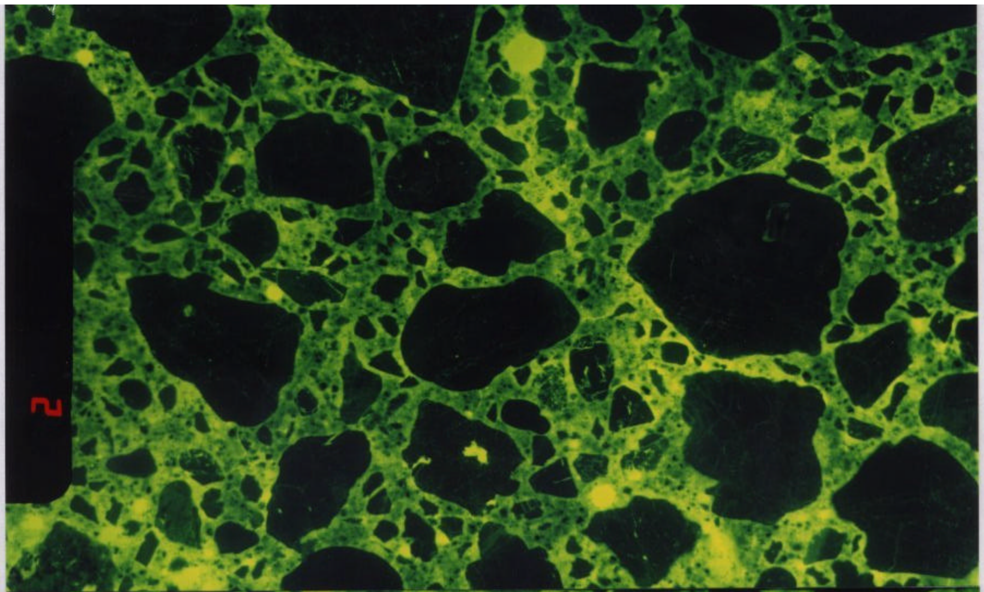
Yellow, round air voids. Edged and rounded aggregates. The paste with some partly hydrated particles of cement.
Magnification: 100X.

0.1mm

13

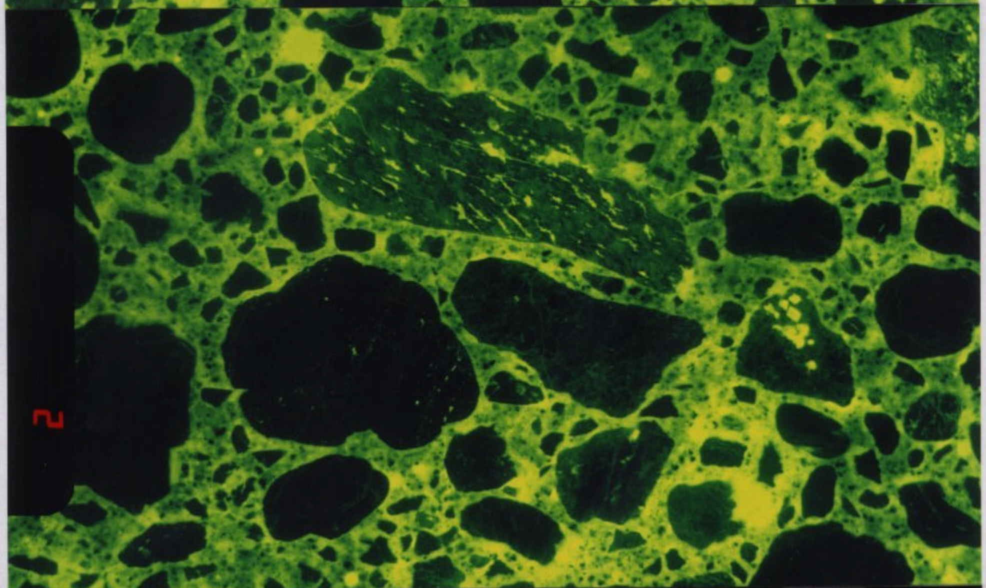
Encl. 3

N1



Area in the edge of the bars. Inhomogenious paste.
The dark particles are sand.
Magnification: 25X.

1mm

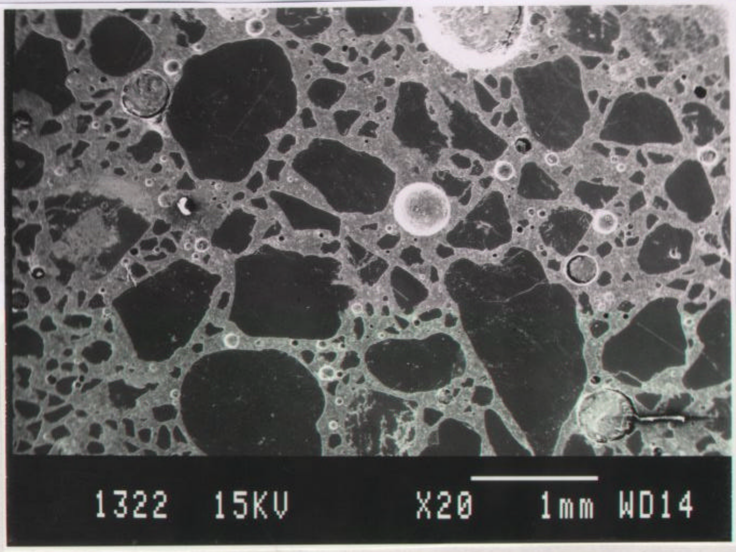


Area in the middle of the thin section with homogenious paste. Porous paste near air void. Magnification: 25X.

Edged and rounded aggregates. The paste with some partly hydrated particles of cement. Magnification: 100X.

0,1mm

15

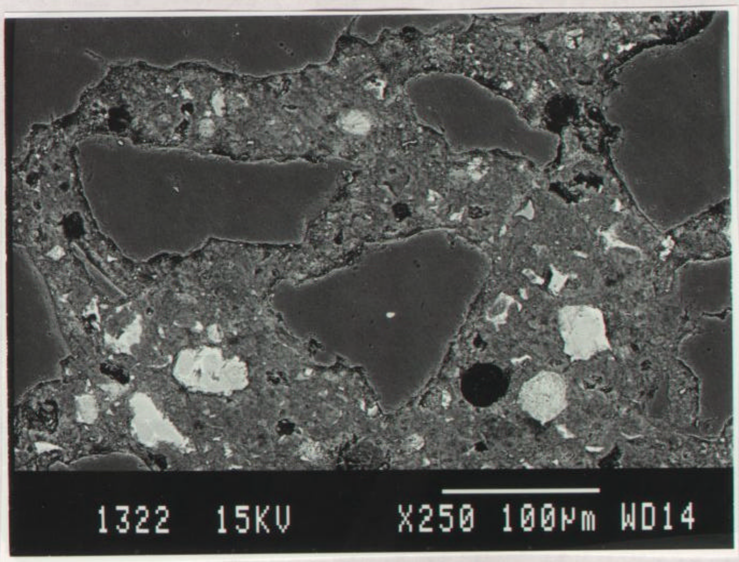


Encl. 4

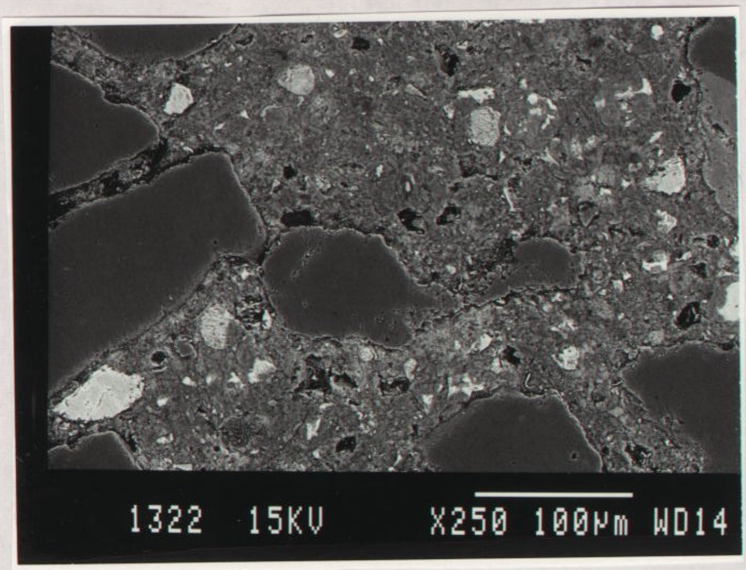
Electron microscope photos:

Air voids: Epoxy filled is black, unfilled white.
Aggregates: Dark grey. Paste: Grey. Unhydrated part. of cement: Light grey.

H1
Magnification: 20X.



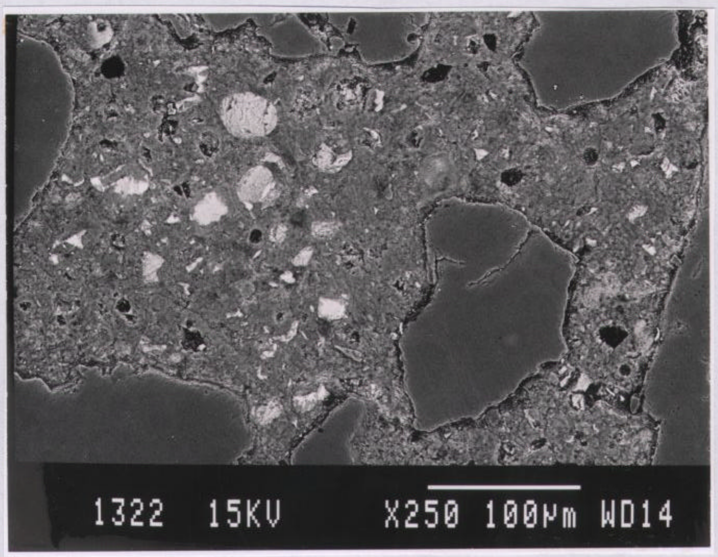
Magnification: 250X.



Magnification: 250X.

Dok.nr.

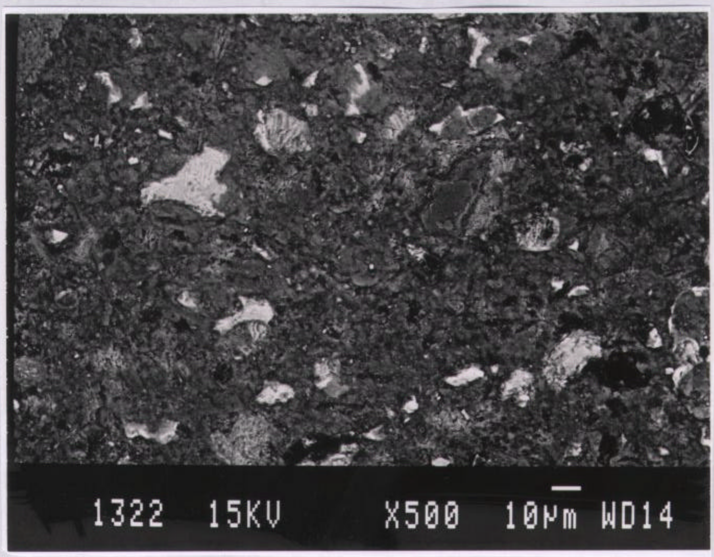
15



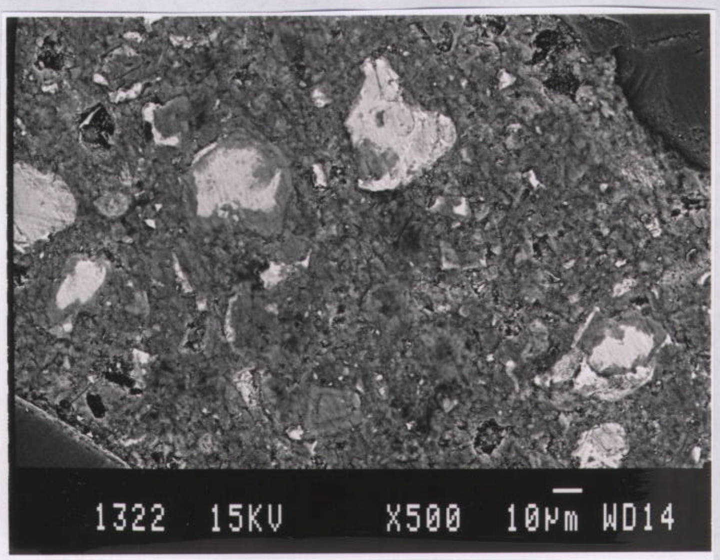
Encl. 5

<u>Electron microscope photos:</u>
Air voids: Epoxy filled is black, unfilled white.
Aggregates: Dark grey. Paste: Grey. Unhydrated part. of cement: Light grey.

H1
Magnification: 250X.



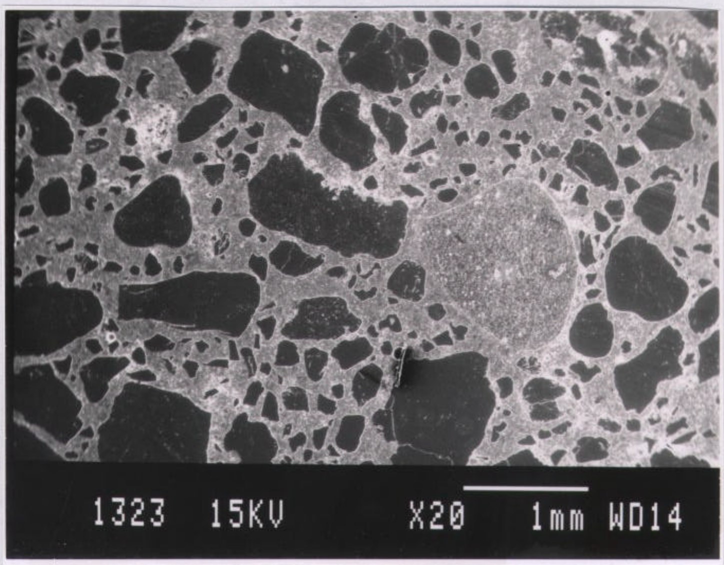
Magnification: 500X.



Magnification: 500X.

Dok.nr.

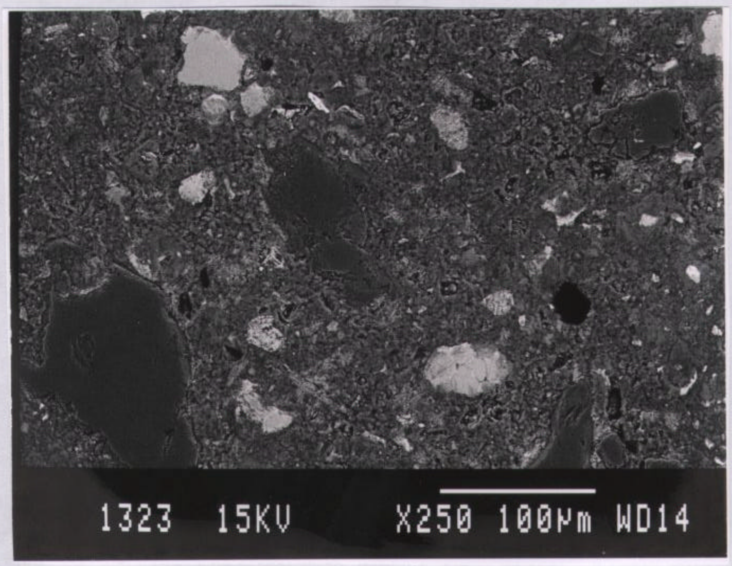
17



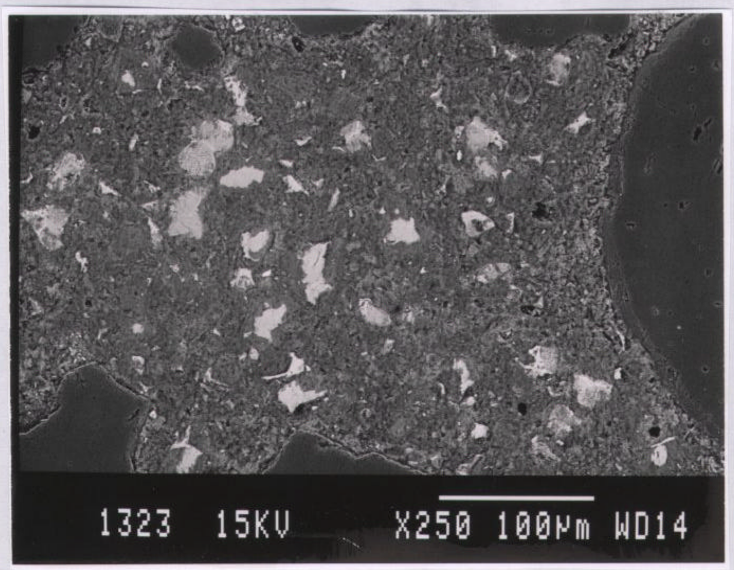
Encl.6

<u>Electron microscope photos:</u>
Air voids: Epoxy filled is black, unfilled white.
Aggregates: Dark grey. Paste: Grey. Unhydrated part. of cement: Light grey.

N1
Magnification: 20X.



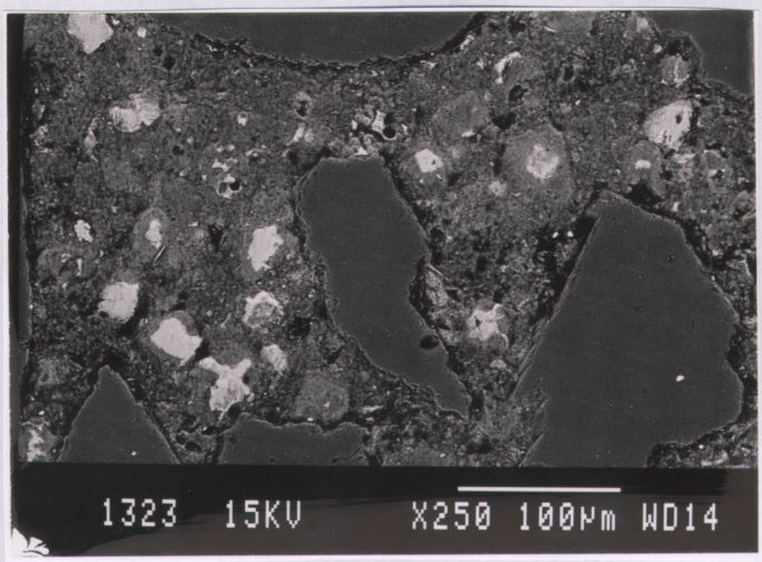
Magnification: 250X.



Magnification: 250X.

Dok.nr.

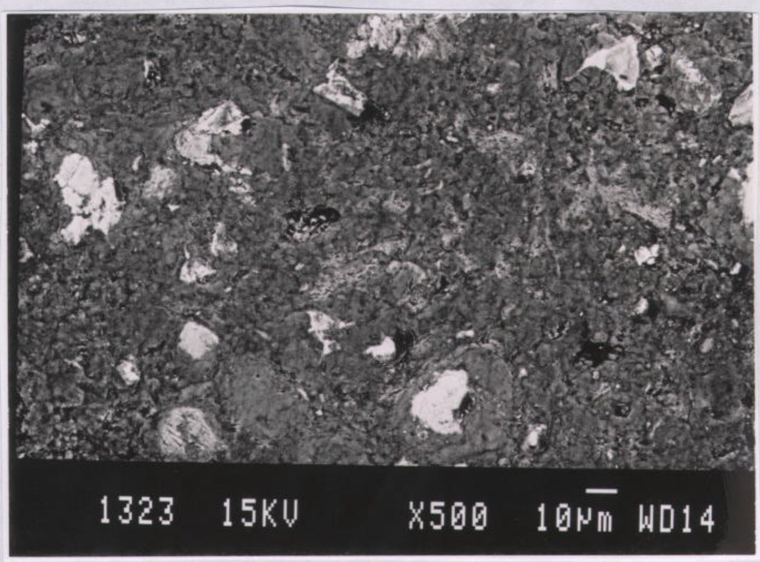
17



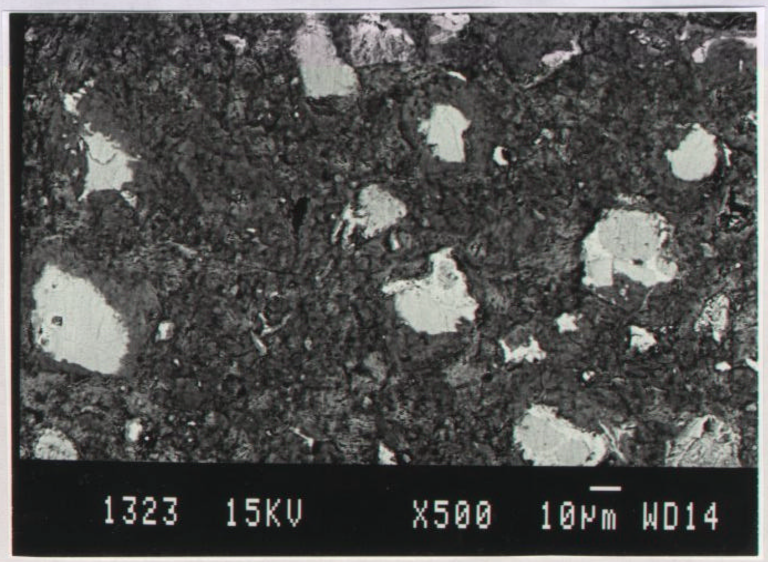
Encl. 7

Electron microscope photos:
Air voids: Epoxy filled is black, unfilled white.
Aggregates: Dark grey. Paste: Grey.
Unhydrated part. of cement: Light grey.

N1
Magnification: 250X.



Magnification: 500X.

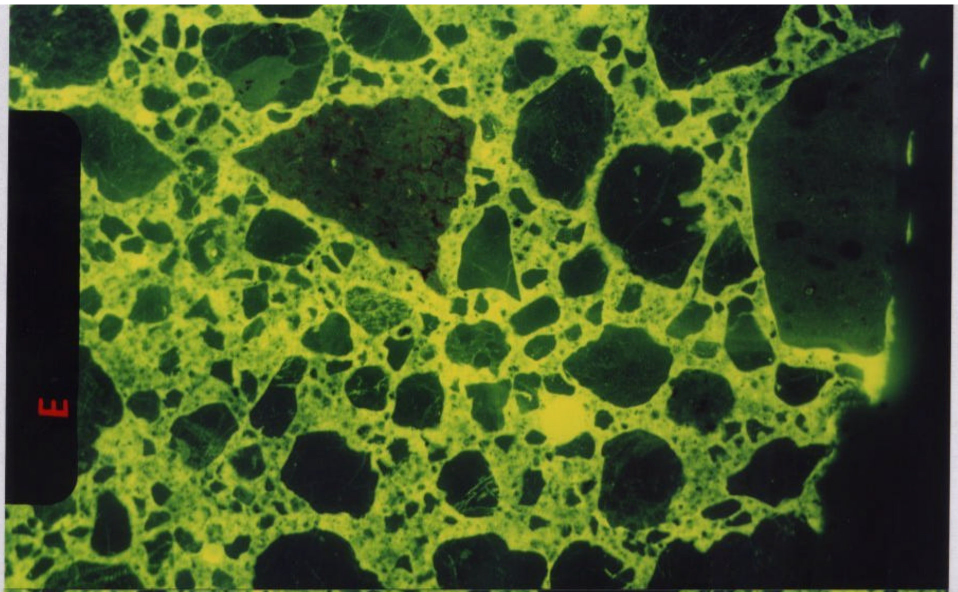


Magnification: 500X.

Dok.nr.

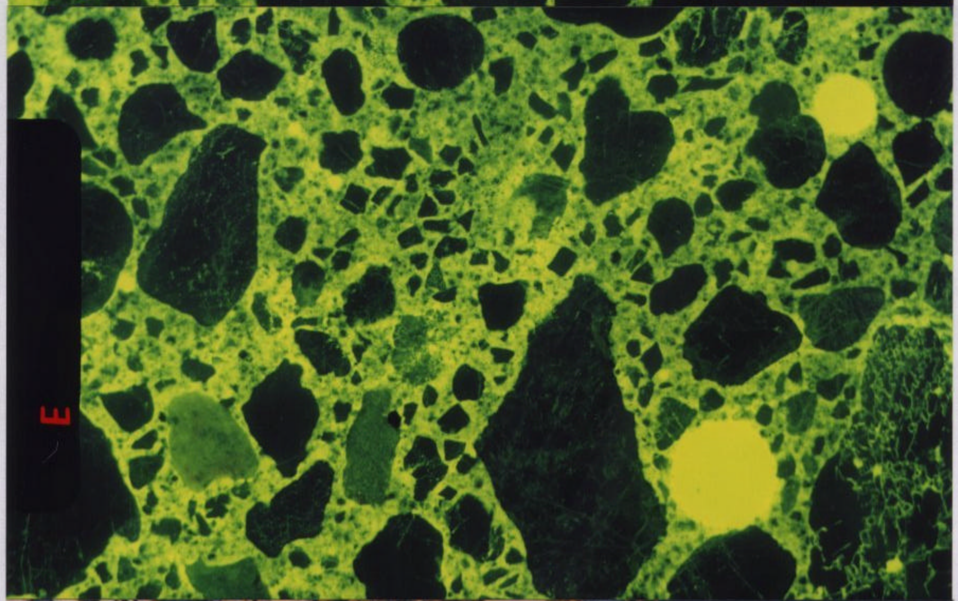
Encl. 8

H3

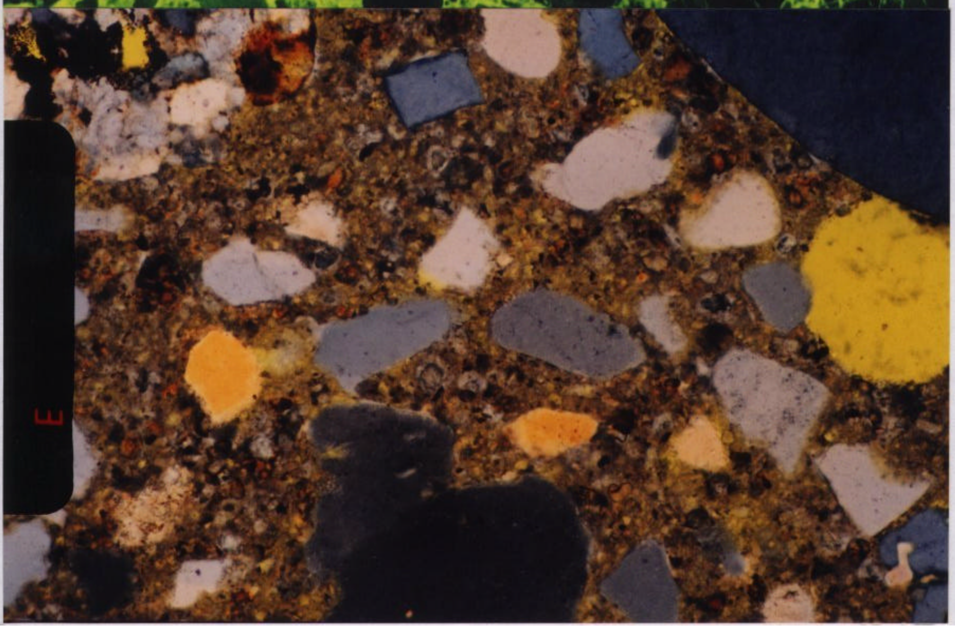


Area in the edge of the bar (to the right). Porous paste and round air void. The dark particles are sand. Magnification: 25X.

1mm



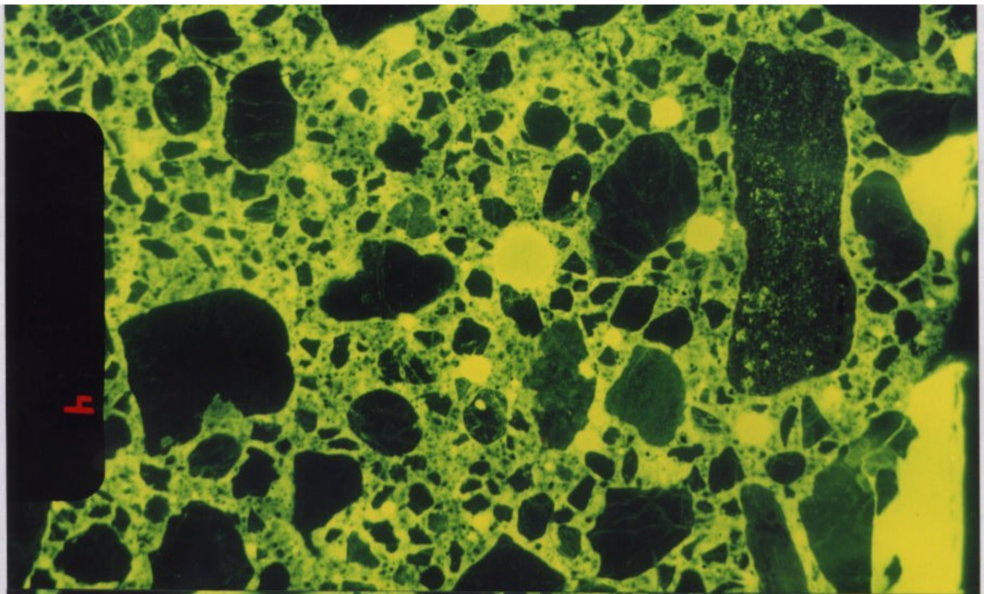
Area in the middle of the thin section. Porous paste and rounded air voids. Some porous particles of sand. Magnification: 25X.



Yellow, round air void. Edged and rounded aggregates. The paste with some particles of cement, partly hydrated. Magnification: 100X.

0.1mm

19

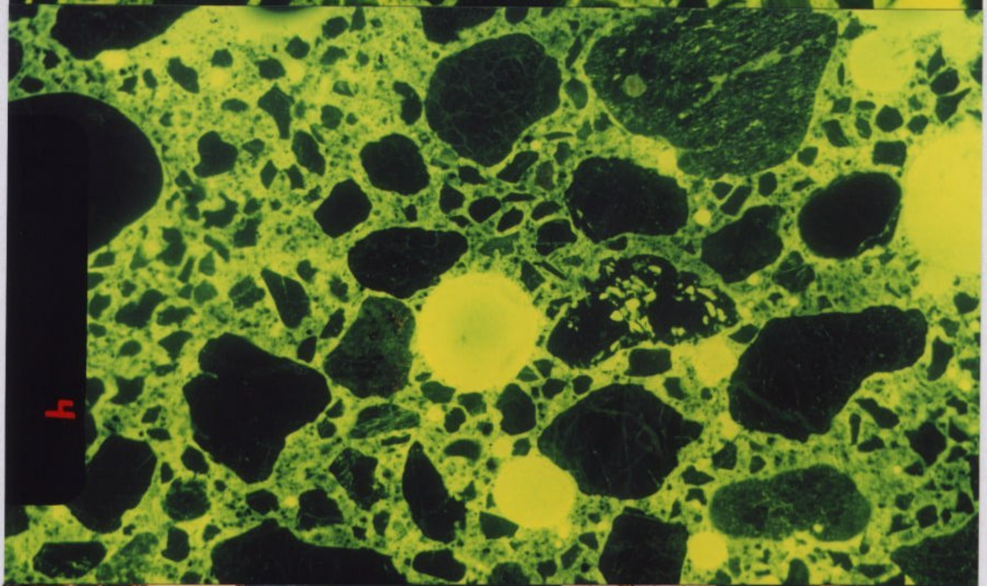


Encl. 9

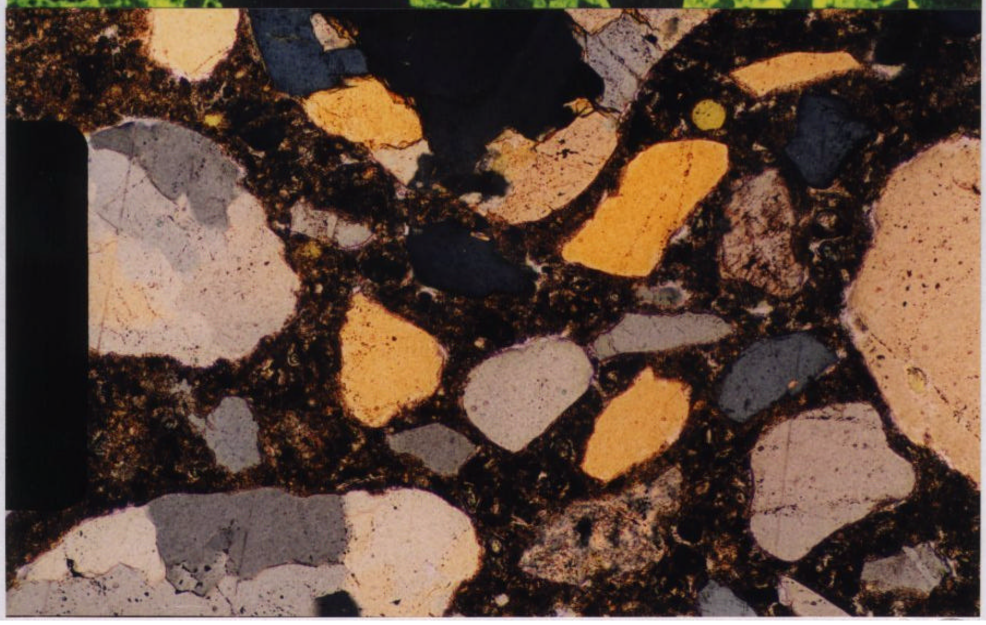
D1

Area in the edge of the bars. Porous paste and rounded air voids. The dark particles are sand.
Magnification: 25X.

1mm



Area in the middle of the thin section. Porous paste and rounded air voids. Some porous part. of sand.
Magnification: 25X.



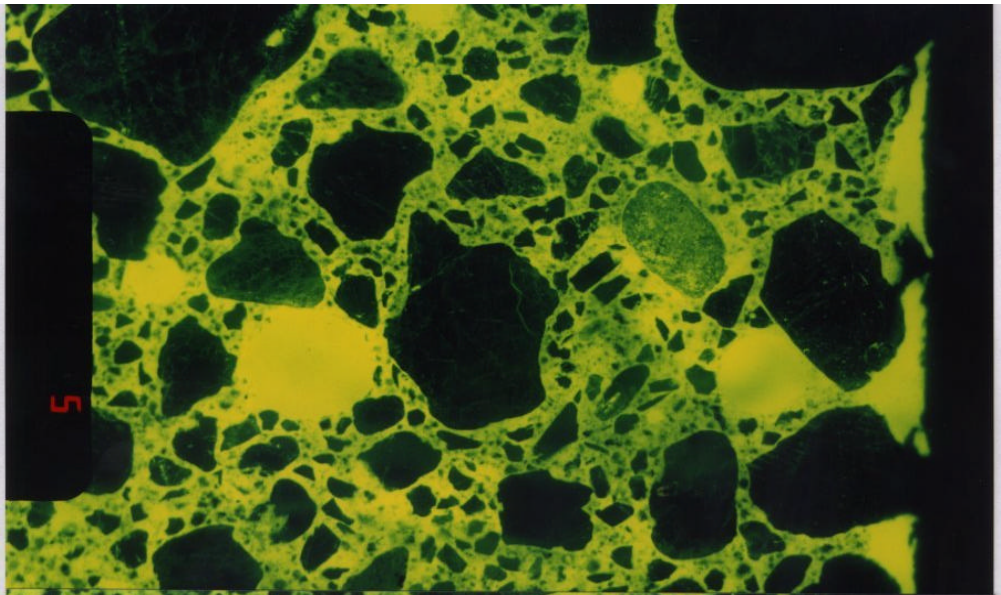
A small yellow, round air void. Edged and rounded aggregates. White gel of silica in the paste and near the aggregates.
Magnification: 100X.

0.1 mm

20

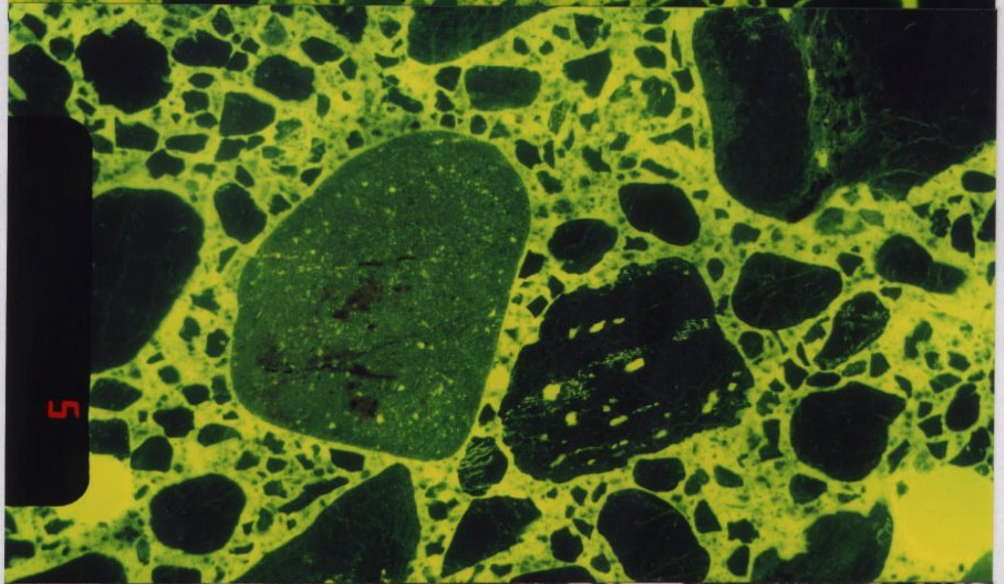
Encl.10

H5

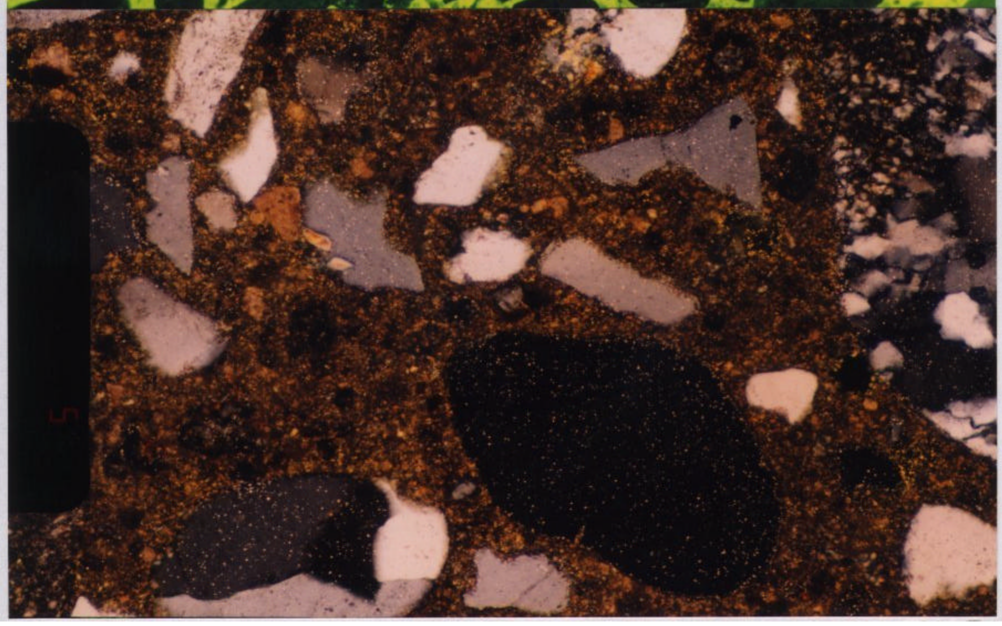


Area in the edge of the bars. Porous paste and rounded air voids.
The dark particles are sand particles. One porous part. of sand.
Magnification: 25X.

1mm



Area in the middle of the thin section. Porous paste and rounded air void. Magnification: 25X.



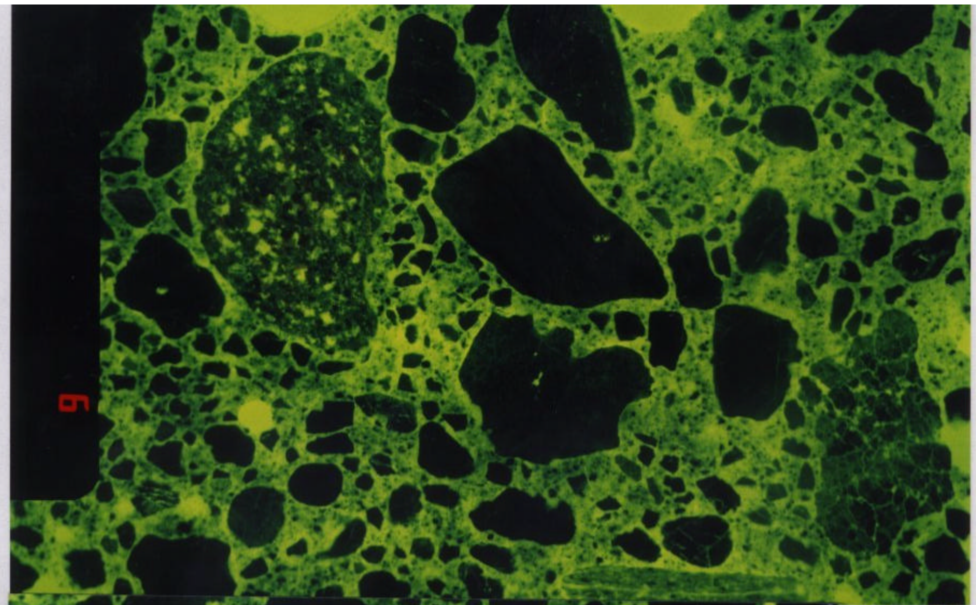
Edged and rounded aggregates. The surface of the thin section covered with secondary $Ca(OH)_2$, caused by the preparation.
Magnification: 100X.

0.1mm

21

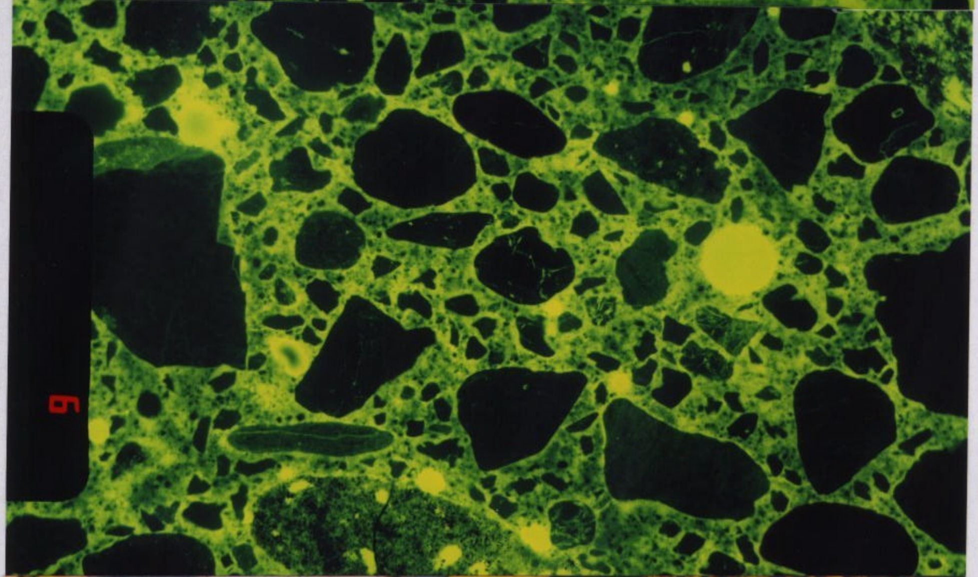
Encl.11

H6



Area in the edge of the bars. Porous paste and rounded air voids. The dark particles are sand. Some porous part. of sand. Magnification: 25X.

1mm



Area in the middle of the thin section. Porous paste. Round and irregular air voids. Magnification: 25X.

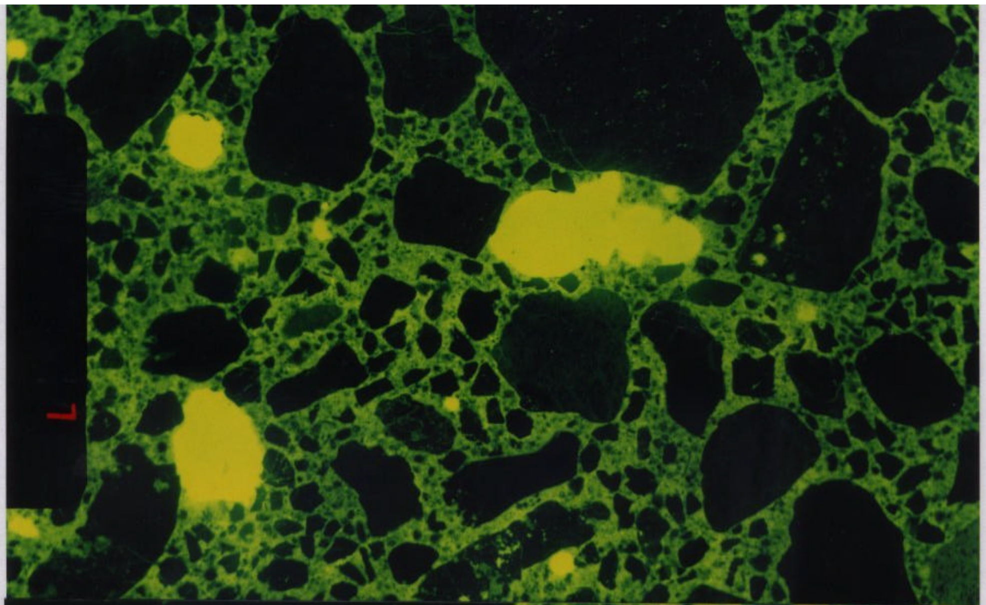
Edged and rounded aggregates. A porous particle of sand with iron in the right corner. Magnification: 100X.

0.1mm

22

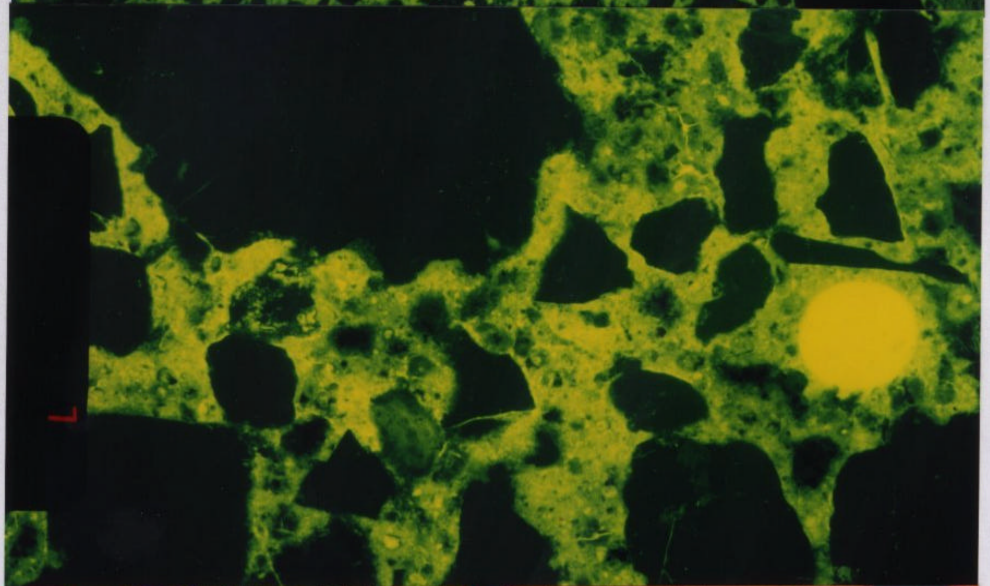
Encl.12

H7



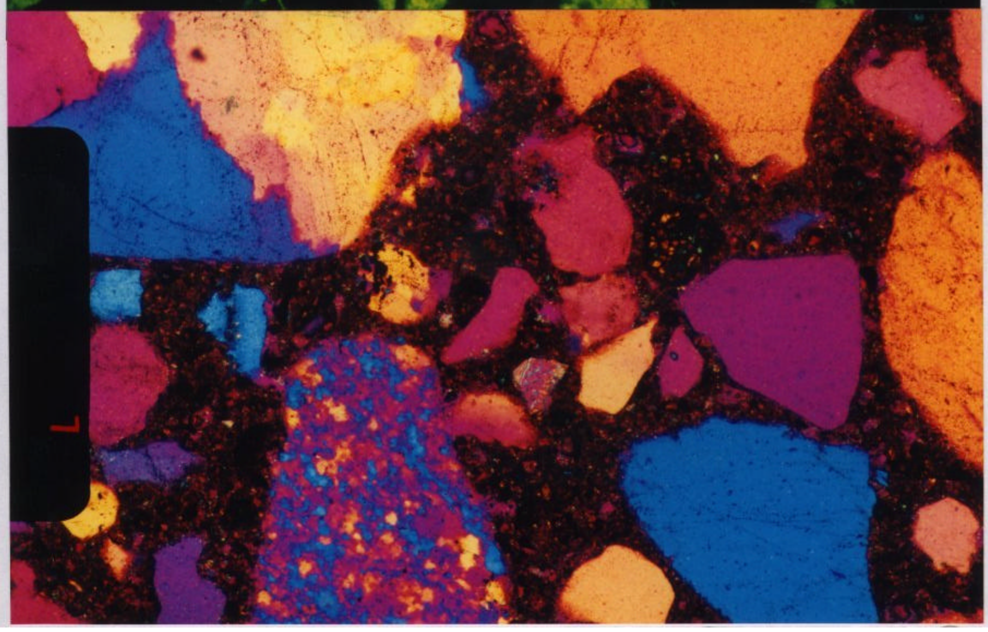
Area in the middle of the thin section. Porous paste, rounded and irregular air voids. The dark particles are sand. Magnification: 25X.

1mm



Fine cracks in unhydrated particles of cement (in the upper right corner). Magnification: 100X.

0,1mm

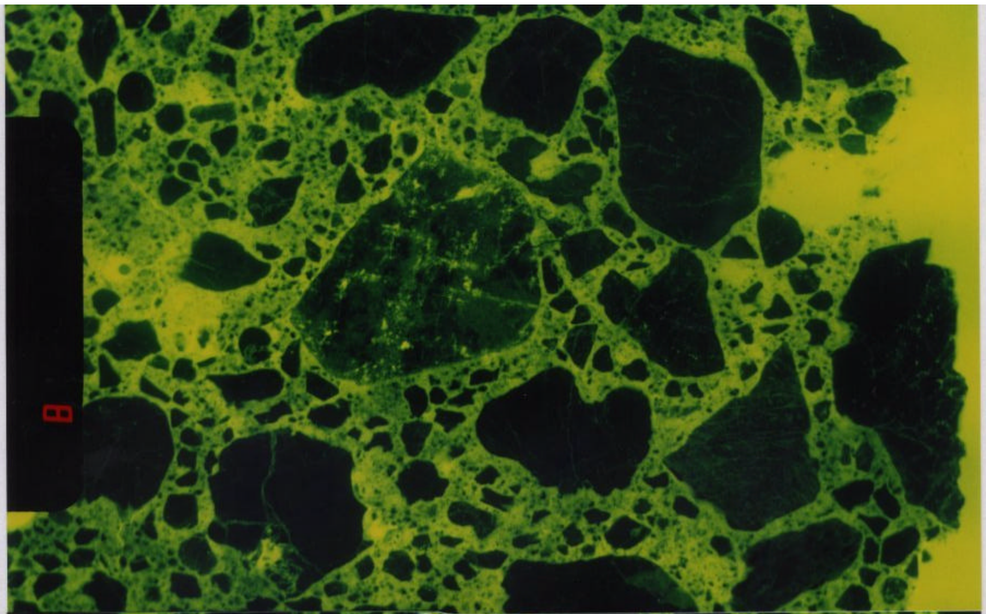


Edged and rounded aggregates. A coarse, unhydrated particle of cement (to the right in the middle of the photo). Magnification: 100X.

23

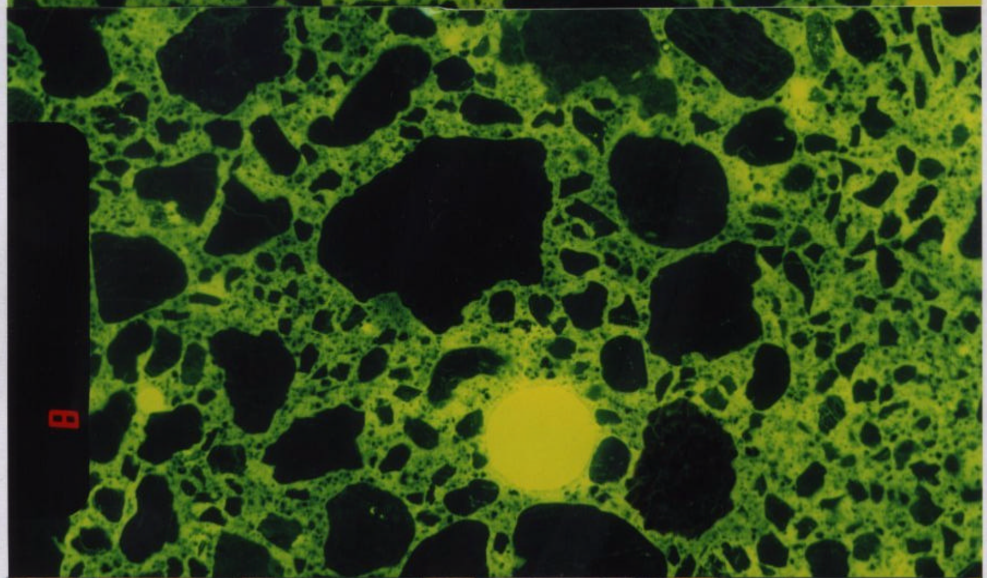
Encl.13

N2

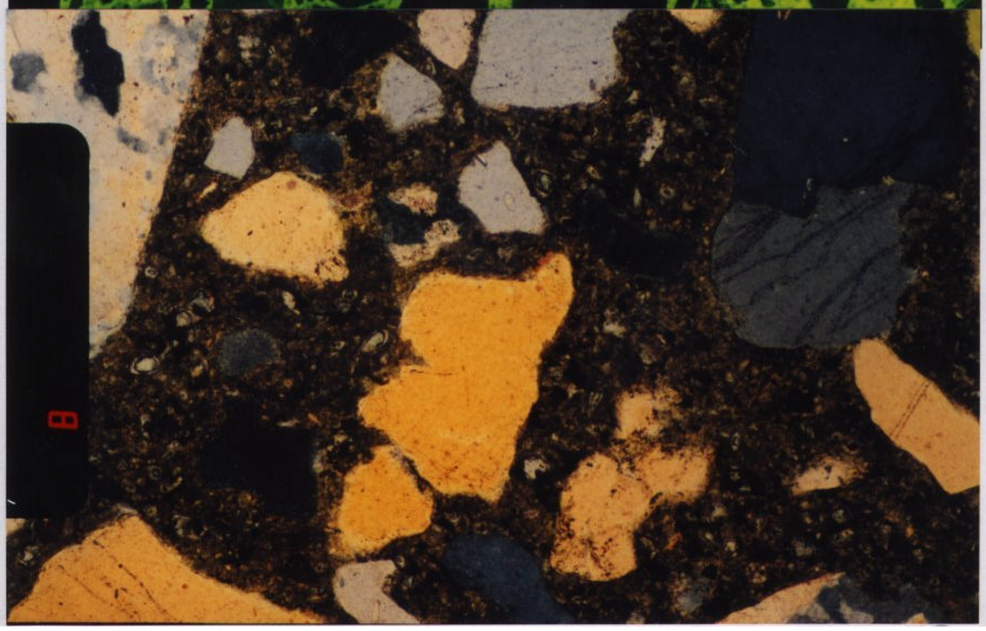


Area in the edge of the bars. Porous paste. The dark particles are sand. One porous part. of sand. Magnification: 25X.

1mm



Area in the middle of the thin section. Porous paste and rounded air voids. Magnification: 25X.

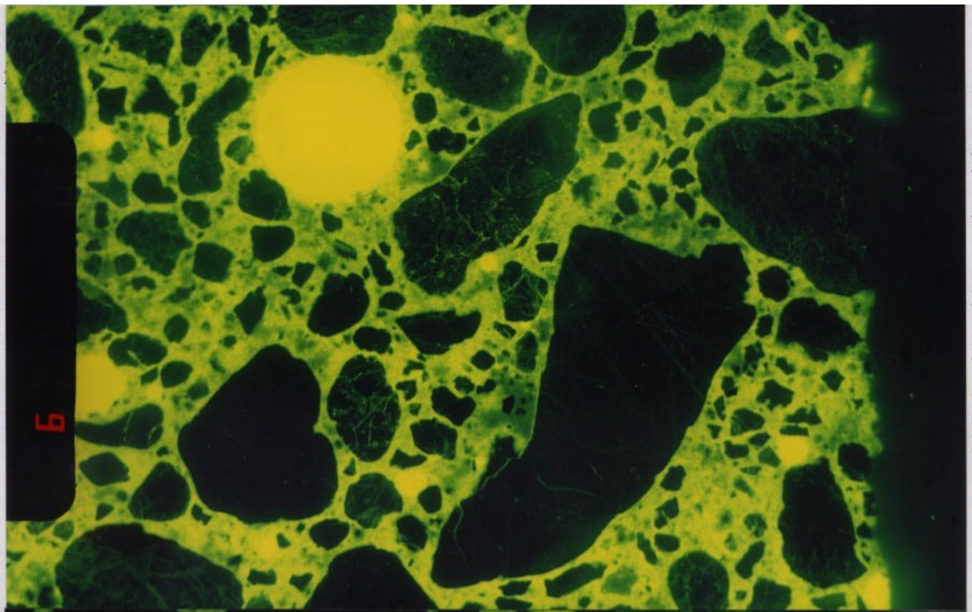


Edged and rounded aggregates. Some unhydrated and partly hydrated particles of cement in the paste. Magnification: 100X.

0.1mm

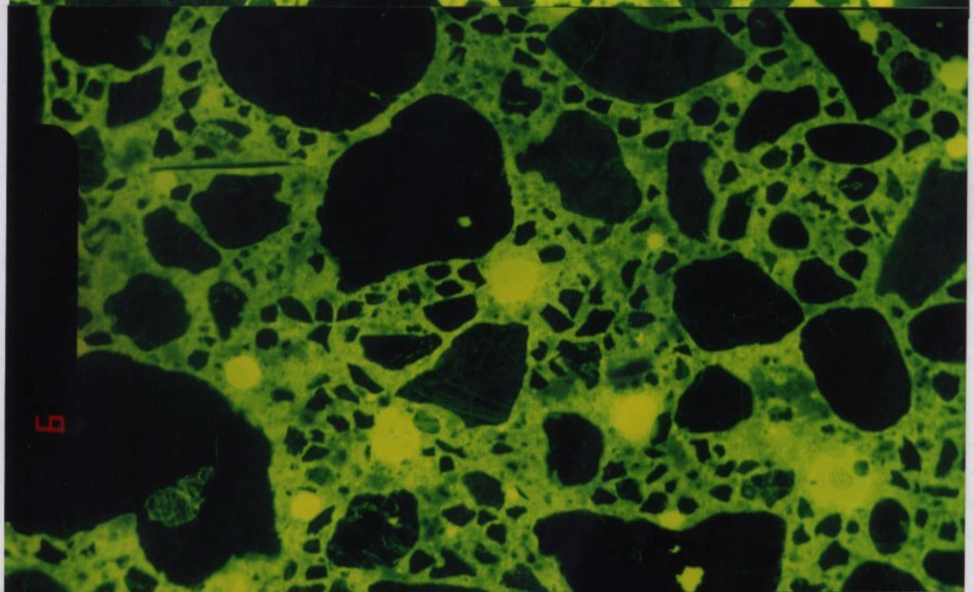
Encl.14

W1

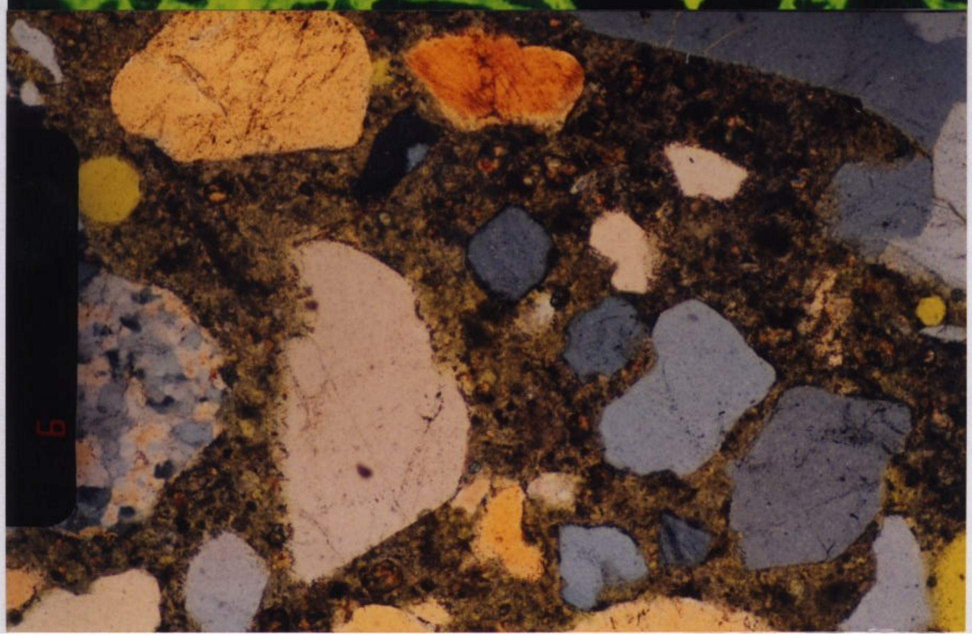


Area in the edge of the bars. Porous and inhomogenious paste. The dark particles are sand. Some part. of sand with fine cracks. Magnification: 25X.

1mm



Area in the middle of the thin section. Porous paste and rounded air voids. Magnification: 25X.

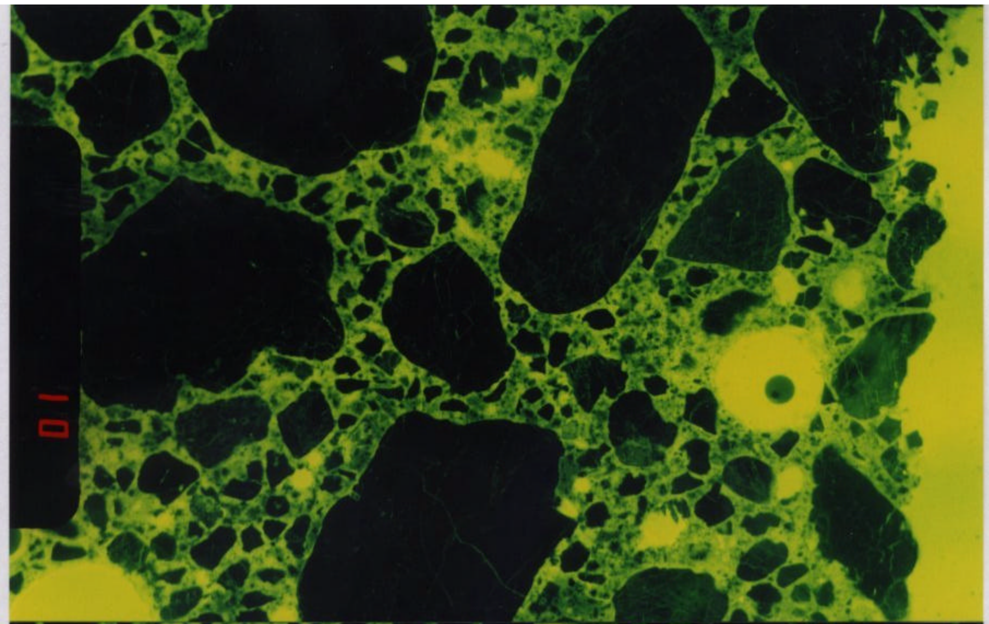


Edged and rounded aggregates. A number of unhydrated and some partly hydrated particles of cement in the paste. Magnification: 100X.

0.1mm

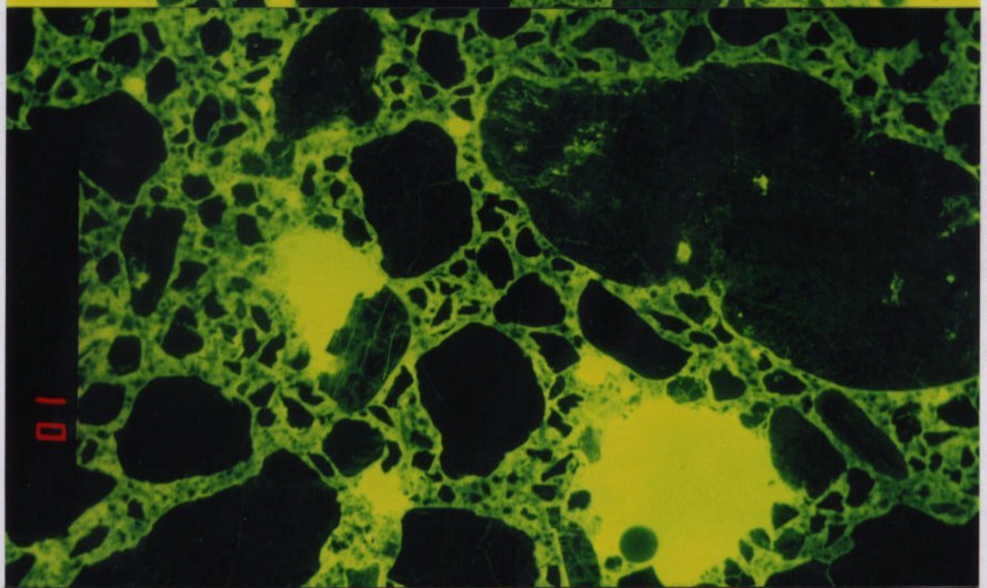
Encl.15

D2

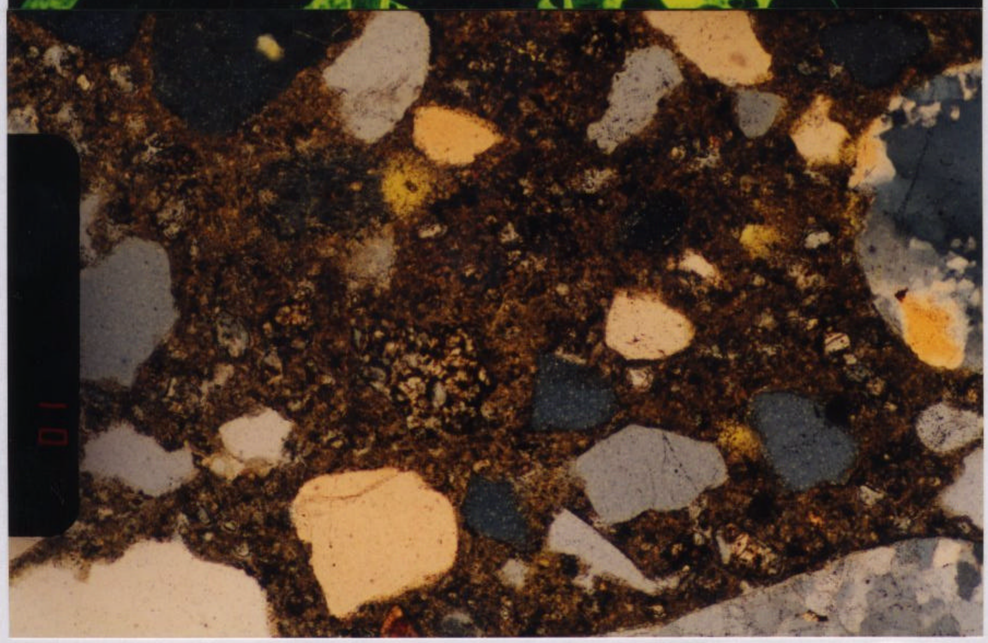


Area in the edge of the bars. Porous and inhomogenious paste. Round and irregular (small) air voids. The dark particles are sand. Magnification: 25X.

1mm



Area in the middle of the thin section. Porous paste. Round and irregular air voids. Magnification: 25X.



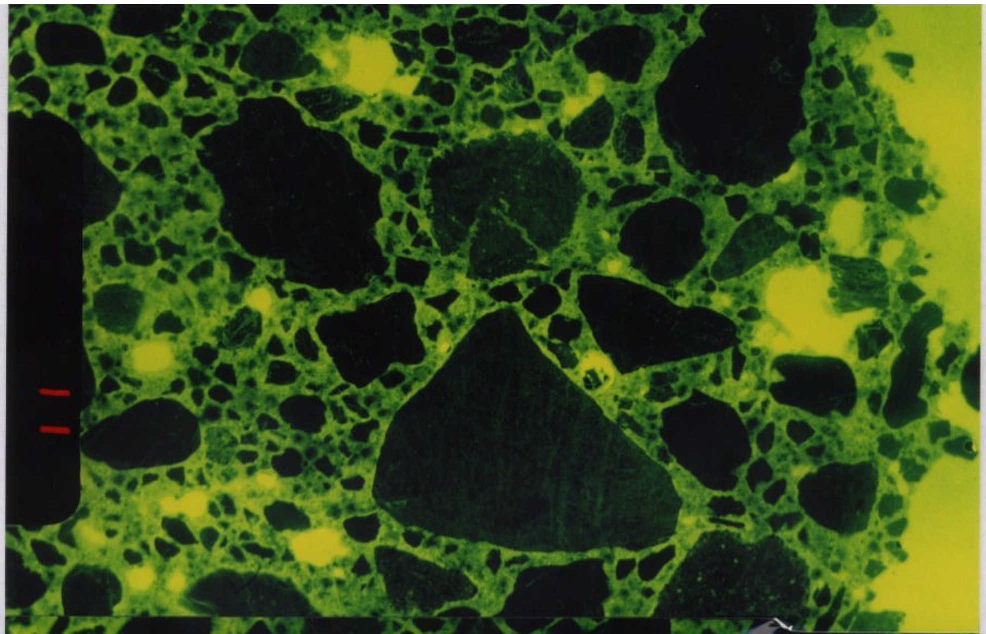
Edged and rounded aggregates. A number of unhydrated and some partly hydrated particles of cement in the paste. A coarse particle of unhydrated cement in the middle. Magnification: 100X.

0.1mm

26

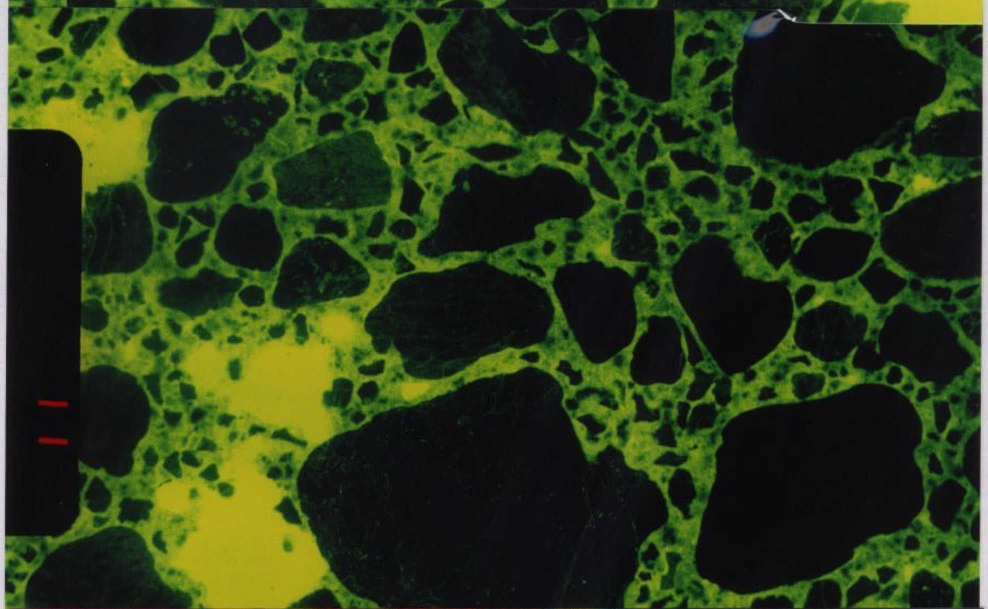
Encl.16

W2

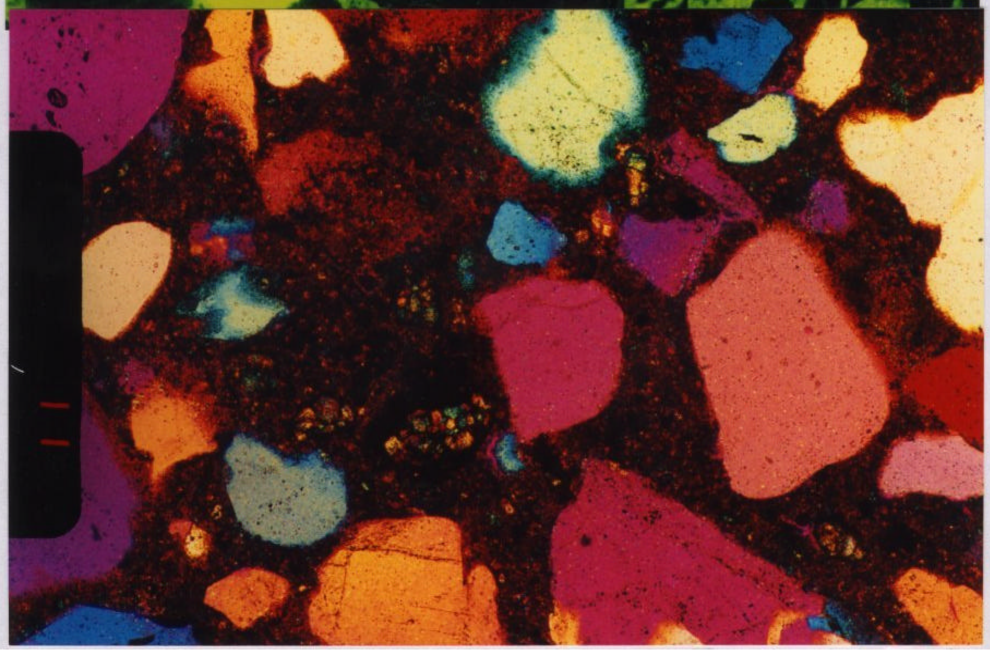


Area in the edge of the bars. Porous paste. The dark particles are sand. Several round and irregular air voids. Magnification: 25X.

1mm



Area in the middle of the thin section. Irregular air voids are seen. Magnification: 25X.

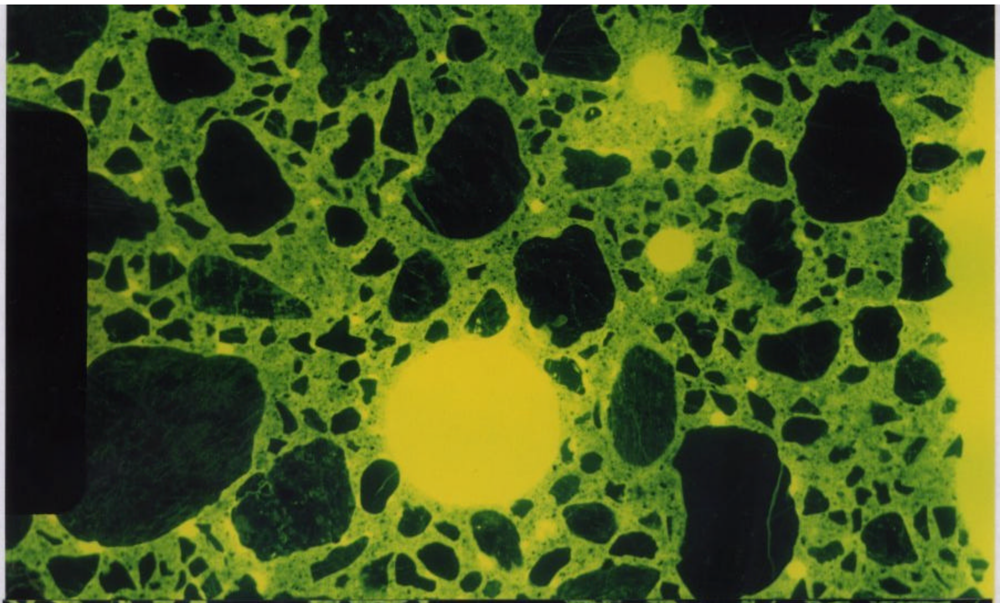


Edged and rounded aggregates. Some coarse particles of unhydrated cement in the middle of the photo. Magnification: 100X.

0.1mm

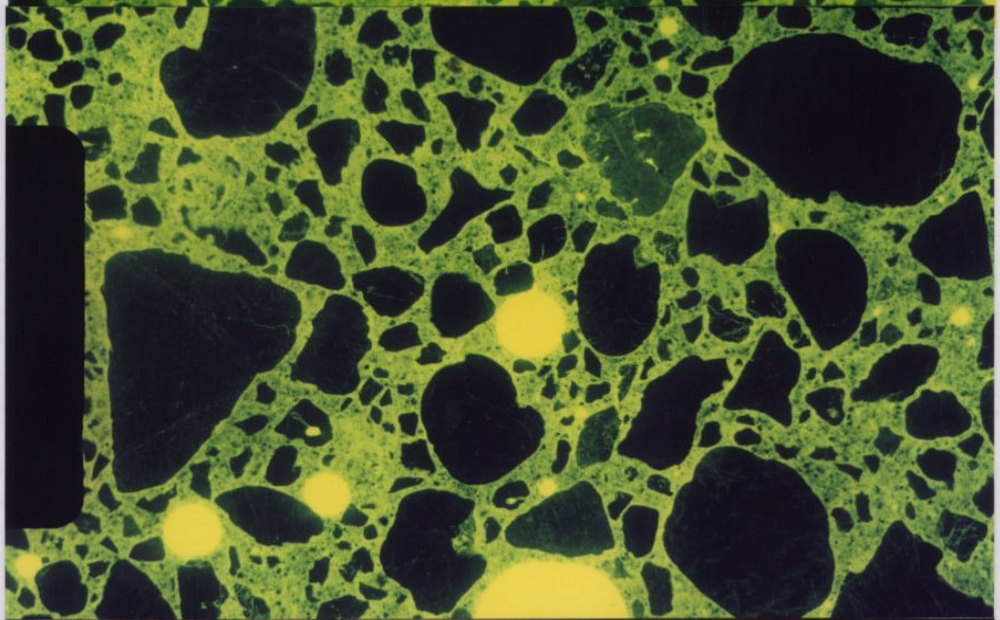
Encl.17

H9

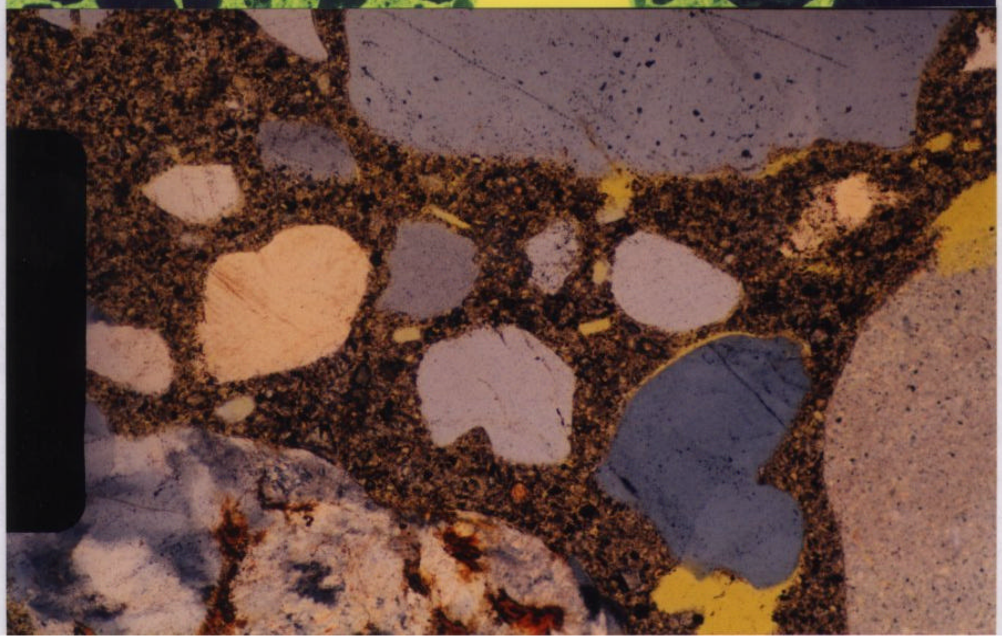


Area in the edge of the bars. Denser past than most of the other samples.
The dark particles are sand. Round air voids and som small irregular air voids.
Magnification: 25X.

1mm



Area in the middle of the thin section. Round air voids are seen.
Magnification: 25X.



Edged and rounded aggregates.
Only a few unhydrated particles of cement (belite).
Magnification: 100X.

0,1mm

28

ANNEX 3 – BACKGROUND ON LEACHING TEST METHODS

3.1 Short description of test methods

NEN 7341 Availability Test [17]: Dutch standard extraction test for assessment of maximum leachability (NNI, 1995). The waste is ground to < 125 µm and extracted in two steps of L/S = 50 l/kg each with demineralized water at pH = 7 (the first extraction) and pH = 4 (the second extraction), respectively. pH is kept constant by feed-back control and addition of HNO3 or NaOH. The contact time in each extraction is 3 hours. The two extracts are combined prior to analysis. The acid consumption is recorded to be able to calculate the acid neutralization capacity.

pH dependence leach test: This test provides information on the pH sensitivity of leaching behaviour of the material. The test consists of a number of parallel extractions of a material at an L/S of 5 or 10 during 24 hours at a series of preset pH values. Since pH is one of the main leaching controlling parameters, the information can be used to evaluate the reproducibility in testing (resulting from measurement at steep concentration **-** pH slopes) and to provide information on the sensitivity to pH in specific field scenarios. The acid neutralization capacity (ANC) derived from the test is a useful additional property in this respect. For material characterization this has been proven to be a very useful method [11,12]. The method is currently standardized in the framework of CEN TC 292 WG6 (WI 292015[21]).

NEN 7345 Tank leach test [18]: This test is a procedure to evaluate the release from monolithic material by predominantly diffusion control (e.g. exposure of structures to external influences). This distinction is necessary, as the transport limitations set by a solid form result in a significantly lower environmental impact than derived from crushed material. This condition is valid as long as the product retains its integrity. To assess the behaviour after disintegration or demolishing the information obtained in the pH static leach test is most relevant. In this situation the pH is likely to change to more neutral conditions.

NEN 7345 modified to address the leaching under conditions where the external solution dictates the pH. The only modification applied here is the flushing of the leachant with air during the leaching process to ensure neutral pH conditions in the eluate at all times. All other aspects of the test remain the same.

Compliance leaching test EN 12457-3. CEN TC 292 compliance test for granular materials EN 12457 [50] - has been recently validated [49]. Part 3 consists of two extraction steps at L/S=2 and subsequently at cumulative fraction L/S=10. The contact time is 24 hours. In the hierarchy of CEN TC 292, this is a compliance test (level 2 test).

Compliance leaching test EN 12457-4. CEN TC 292 compliance test for granular materials EN 12457 [26] - has been recently validated [27]. Part 4 consists of an extraction step L/S=10 on material size-reduced to < 10 mm. In the hierarchy of CEN TC 292, this is a compliance test (level 2 test).

Compliance monolith leach test [28]. Although still in development by CEN TC 292 WG2, the main test features are: the specimen is leached after vacuum saturation with demineralised water at an liquid to area ratio of 5, eluates are produced after 6, 24 and 48 hours and subsequently analysed. These steps correspond with the first fractions of NEN 7345.

Concise leaching test [19,20] consisting of 4 extractions at respectively own pH and L/S=2, own pH and L/S=10, controlled pH=7 and L/S=10 and controlled pH at L/S=4. The particle size reduction normally applied for this test is 95% <2 mm. In the ECRICEM I study, an alternative particle size distribution was applied. The combination of these leaching steps allows conclusions on the pH dependence of leaching and on the dominant release mechanisms (solubility or availability control).

Annex 3 BACKGROUND ON LEACHING TEST METHODS

Pore water test: The pore water tests were carried out with the special apparatus illustrated in the figure A3.1, with which the pore water can be extracted from hardened cement past, mortar and – to a limited extent concrete with a powerful hydraulic press at pressures up to 5000 bar.

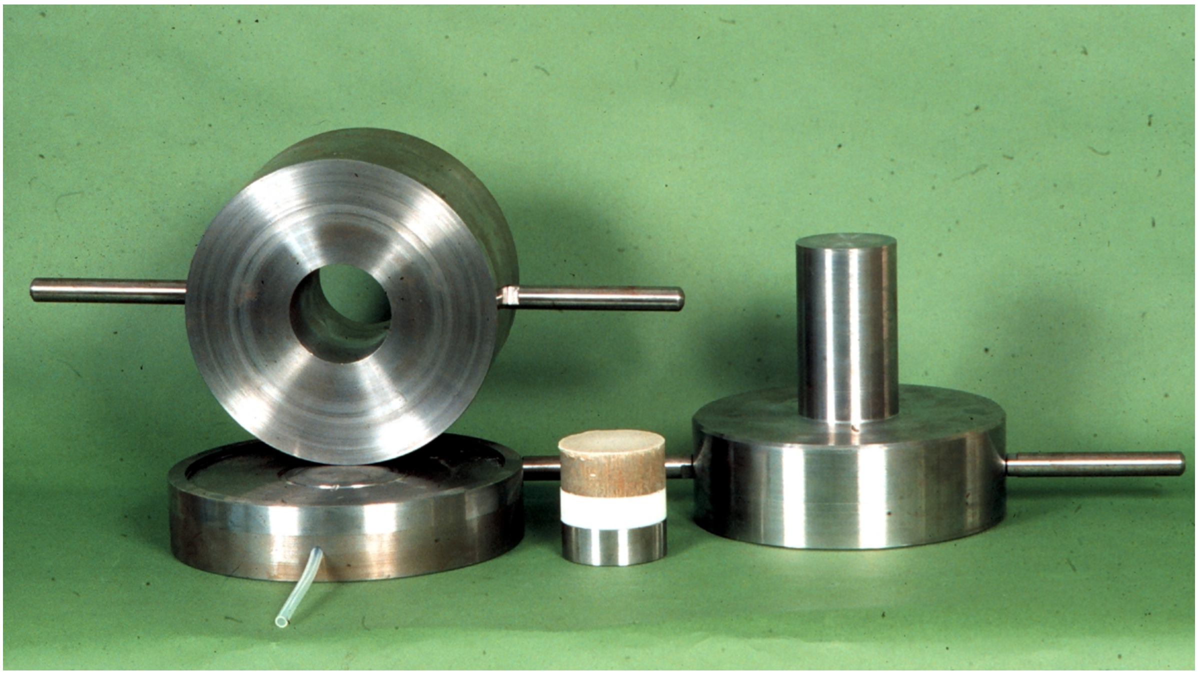


Figure A3.1: Apparatus for expression of pore water.

3.2 Operation and uses of the pH dependence test.

3.2.1 Clarification of the two modes of operation of the pH dependence test

The two modes to carry out a pH dependence leaching test as described in the CEN TC 292 WG6 standard are:

- the batch mode with addition of prior determined quantities of acid or base to reach the desired end pH values.
- the automated mode in which the pH is controlled at pre-selected values over the entire testing period by continuous measurement and automatic addition of acid or base

In figure A 3.2 the typical pH variation during the test is given for an alkaline material controlled at a final pH of 5 by the two modes, which mainly differ in the manner how the final pH is reached. The checking period for reaching equilibrium condition as defined in this standard are illustrated.

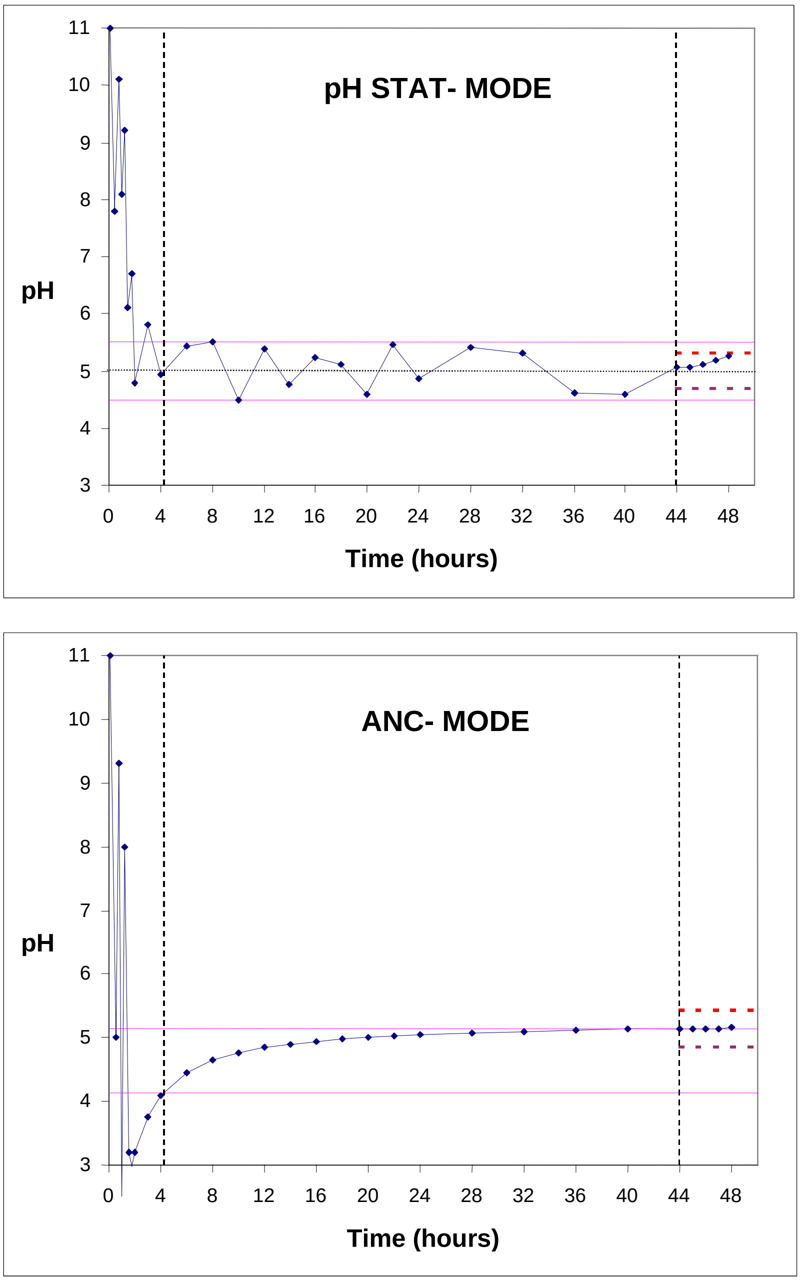


Figure A 3.2.   Typical pH variations during the tests on an alkaline material at a final pH of 5.

3.2.2. Uses of the pH dependence leaching test

Below a number of possible uses of the pH dependence test are provided.

1. Identification of the sensitivity of leaching to pH over the environmentally relevant pH range

The test provides insight in the sensitivity of leaching from a specific material to pH, which has been found to be a major release controlling parameter in virtually all materials. Obviously, the relevant pH range for a given application may be limited. However, for characterization purposes the full pH range from at least 4 to 12 is important as different uses of the information relate to different pH domains. In figure A 3.2 this is illustrated.

2. Identification of the sensitivity to pH variations affecting the repeatability of leaching tests.

In many leaching tests, the material itself dictates the pH conditions in the extract and consequently the leaching. In the pH domain dictated by the materials itself, leaching can be very sensitive to minor changes in pH leading to factors or sometimes order of magnitude differences. These are aspects inherent to the leaching behaviour of materials and the leaching process. It is crucial to be aware of such sensitivities for a given material. The pH domain, in which such sensitivities occur, may vary by element and by material as illustrated in figure A 3.3. (V : pH range 9 - 12).

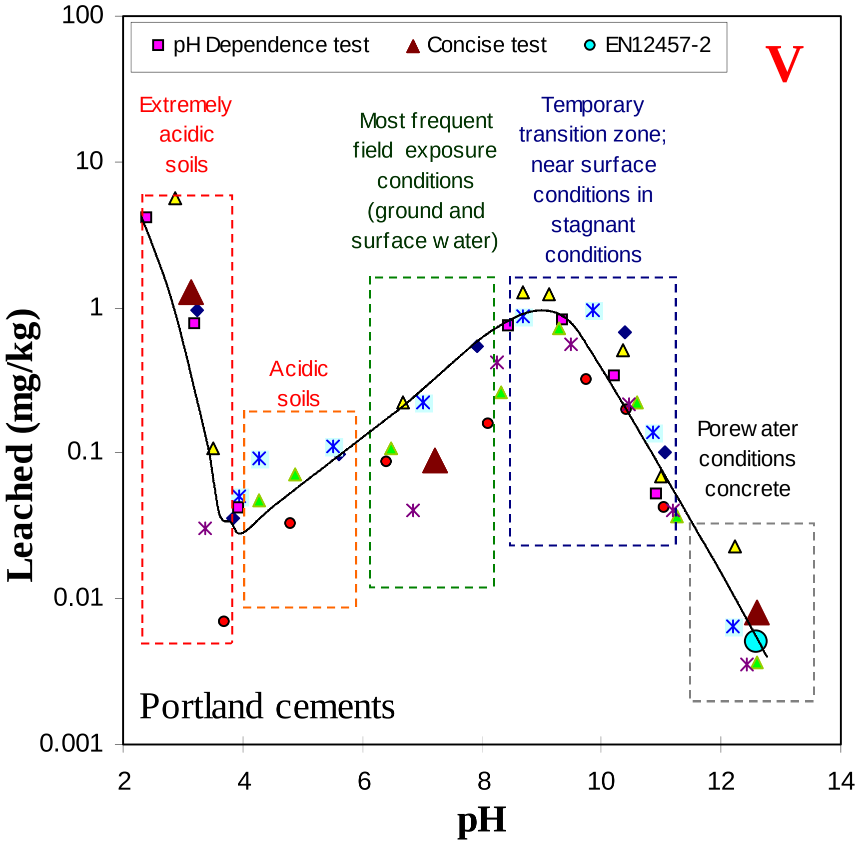


Figure A 3.3. Illustration of relevant pH domains for judging different aspects of a cement mortar as obtained in a pH dependence test. Legend: pH dependence test ANC mode; Concise test - Extractions at own pH, acid pH and neutral pH (matching for own pH with CEN - EN 12457- 2 test results. Identification of use of information in relation to practical applications.

2. Identification of the sensitivity to pH variations affecting the repeatability of leaching tests.

In many leaching tests, the material itself dictates the pH conditions in the extract and consequently the leaching. In the pH domain dictated by the materials itself, leaching can be very sensitive to minor changes in pH leading to factors or sometimes order of magnitude differences. These are aspects inherent to the leaching behaviour of materials and the leaching process. It is crucial to be aware of such sensitivities for a given material. The pH domain, in which such sensitivities occur, may vary by element and by material as illustrated in figure A 3.3. (V : pH range 9 - 12).

3. Basis for the comparison of different (international) leaching tests.

Several studies, in which different leaching tests have been compared, show that the pH dependence test forms the best basis for mutual comparison of leaching tests. As in most leaching tests developed for regulatory purposes pH is the most relevant leachability-controlling factor (see figure A 3.3). Extractions with different mild water leachants and acidic extracts are compared.

4. Basis for chemical speciation and modelling of leaching controlling mineral phases

Data from the pH dependence test can be used in geochemical speciation codes, such MINTEQA2 , GEOCHEM WORKBENCH, or ECOSAT, to quantify the solubility control by specific mineral phases. Besides the library of minerals and their solubility products, parameters to quantify sorption to Fe-oxide phases and models describing complexation with organic matter (particulate and in solution) are available (see figure A 3.4).

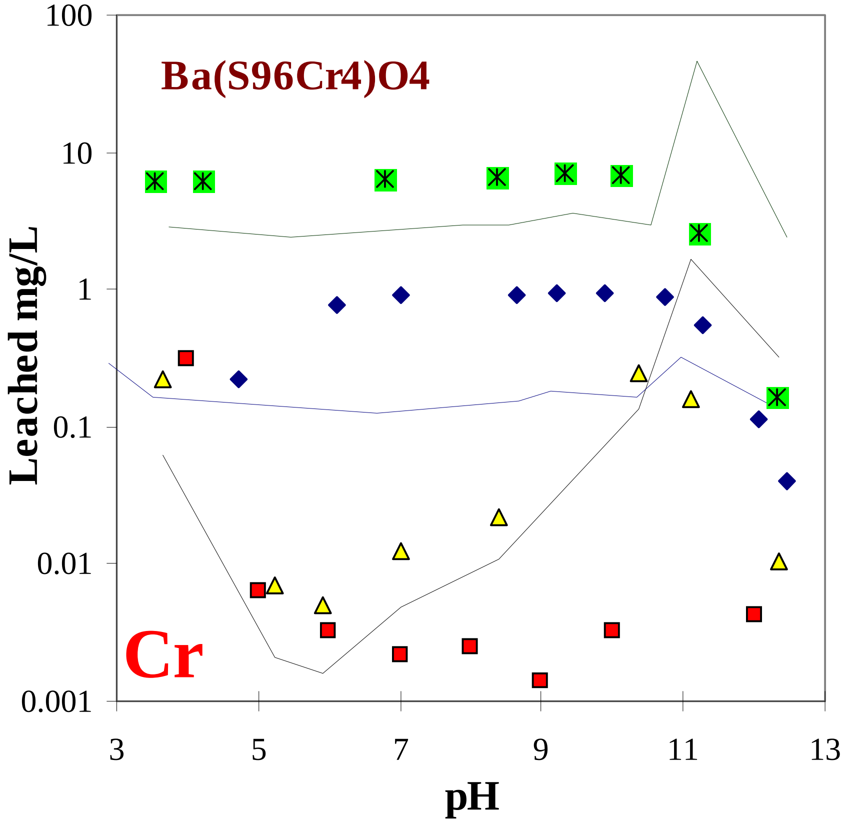


Figure A 3.4 Modelling of the chemical speciation of Cr in eluates from the pH dependence test using the MINTEQA2 model showing a good match between prediction and measurement. This indicates a dominant role of the solid solution of BaSO4.BaCrO4 in these eluates.

5. Mutual comparison of materials across different fields (construction materials, waste materials, soil, sediments, compost, impregnated wood, sludges, etc).

Using pH dependence test information as the basis, the leaching character of different materials can be compared. From such a comparison far more can be deduced with respect to factors potentially controlling the leaching behaviour of materials than results from single extraction tests or time dependent leaching tests ever can. Factors identified as relevant controlling factors can be identified as being relevant to other fields as well. A perceived inorganic waste may show typical behaviour of materials containing organic matter, which would trigger analysis of DOC and lead to conclusions on the possible role of organic complexants.

6. Identification of leaching controlling factors (e.g. redox, DOC, Cl - complexation)

By obtaining information on a wide range of materials with widely varying properties, effects of specific factors can be recognized. Consequently, for unkown materials the pH dependence test provides conclusions on possible reasons for deviating or unexpected behaviour. For instance, Cl can play a major role in the Cd leachability from cement-bound materials.

7. Mutual comparison of separate productions or charges form the same material class

The pH dependence test results can be used very well to identify differences in leaching behaviour within one material class. Obviously, in such cases analysis of the full range is no longer needed. The pH condition to be verified can be selected according to the most relevant condition for the material in a scenario under consideration. In terms of leaching behaviour as a function of pH, materials from regular production processes (primary or secondary material) will tend to show the same leaching character, although between charge variations in release at a given level may occur.

8. *Tool for prediction of long term environmental effects (i.e. pH changes with time).*

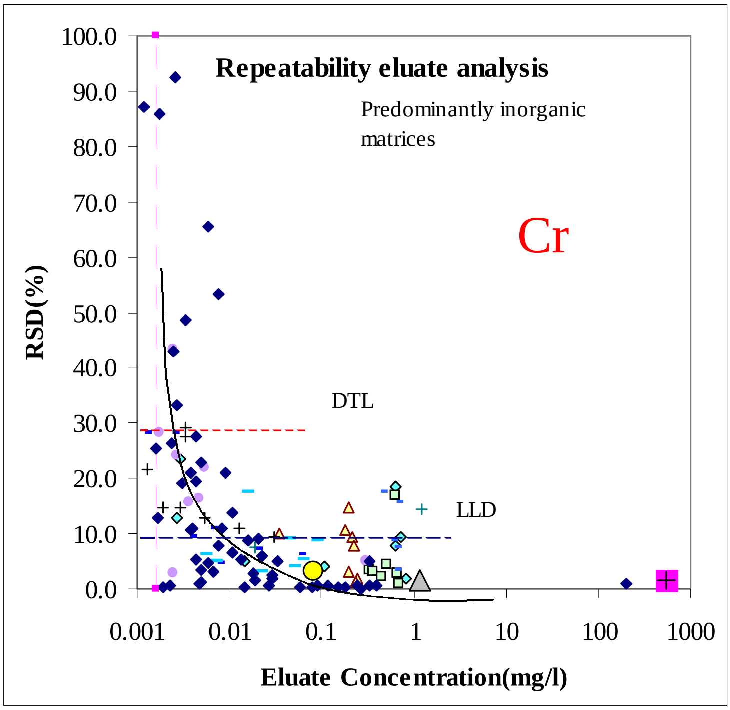
Relations between time dependent (column tests, tank leach test) and pH dependent leaching tests have been identified in a semi-quantative manner. This implies that there is a possibility to provide predictions (order of magnitude indications) on long term release once the direction and magnitude of change of exposure conditions in terms of pH, redox and DOC are known. It provides the option to tailor test performance to practical exposure conditions. However, this requires a rational choice of relevant conditions, as not all of the intermediate stages are important. Many systems move to relatively stable “equilibrium“ conditions, which implies that the evaluation can be focused on this final condition. For many materials, this is a pH 7 - 8 condition. A crucial first step in this process is to identify whether the material to be evaluated dominates the exposure conditions or the surrounding imposes the exposure conditions on the material. A next crucial aspect is then to establish the changes in material exposure conditions as a function of time and how stable these conditions are over a certain time frame. The acid neutralisation capacity or base neutralisation capacity is an important parameter to be able to quantify the time frame of change of the important parameter pH. In several cases, it has been shown that the real conditions in practice are less critical than a test would indicate; thereby unnecessary limiting application. The pH dependence test can be a very important source of entry data for dynamic behavioural models, for instance under the following relation: solubility = f (pH or meq H+/g) controlled by the equilibrium with the other compounds of the material. This is not possible with literature data

9. Identification of critical components for leaching in relation to regulation

To identify which elements may be critical from a leaching point of view in relation to regulatory thresholds the pH dependence test data provide an ideal tool in 6 - 8 extractions covering the relevant pH range for the materials to be evaluated. The relevant pH range for the material may vary for one material between applications, but may also vary between materials. (e.g. pH 5-12 or in other cases pH 8 - 12). This test allows a quick screening in a few days and provides information, which elements are so close to the regulatory limit that that they have to be marked as potentially critical.

10. Use of pH dependence test data for quality control of the analytical method.

As a result of the often very wide concentration ranges measured in a pH dependence leaching test, the test has specific possibilities to assess the performance of the analytical technique employed. The influence of the eluate matrix on the analytical capabilities is often an unknown factor. By running a pH dependence leaching test in duplicate on a given matrix valuable information on the sensitivity of analysis of specific components due to matrix interference can be identified. By plotting the data in a concentration - relative standard deviation plot and inserting the desired levels of detection and determination limit, matrix influences and heterogeneity aspects of the material studied can be identified. For a given analytical technique, measurement without interference will lead to the same basic graph, which can be used as an equipment specific property. Matrix effects can be recognized by a shift in the curve. Heterogeneity’s can be identified by incidental excursions well above the general curve at concentrations which should be measured with greater accuracy (see figure A 3.5).



Figuur A 3.5. Relative standard deviation of Cr as a function of the concentration in extracts for various materials (analysed by ICP). Results derived from validation trails and other studies, in which multiple analysis were performed. (LLD = lower limit of determination, DTL = detection limit)

3.3 Examples of acid and base neutralisation capacities for construction materials

From previous work data on acid - and base neutralisation capacity data have been obtained for a wide range of materials. This implies that this previous knowledge can be used in carrying out the pH dependence test. The information provided may not be entirely accurate for the sample under consideration. But the variation within one material class is generally not very large.
In figure A 3.5 acid neutralisation and base neutralisation capacities for some construction materials are given, which can be used as starting point to carry out a pH dependence test. In table 3.1 the underlying data are given (expressed in mol/kg). This information allows the selection of the relevant acid or base strength as well as the approximate amount of acid or base needed for a given sample weight to reach a certain desired end pH. This information can come in the place of the pre-titration as described in Annex B of the standard.
The selection of the acid strength is based on the buffer capacity of the material. In case of low buffer capacity in materials such as soil, metallurgical slag, sintered brick and sintered aggregates, the lowest acid/base strength specified in the standard should be used.
For the automated pH dependence test aimed at reaching a fixed pH, the acid strength is the most crucial parameter. For the pH dependence test with fixed acid/base addition, the proper amounts of acid/ base to be added needs to be determined. Generally more bottles are prepared in this test mode of which the proper end pH values are selected for further analysis.

To calculate the amount of acid or base needed from the ANC / BNC expressed in mol/kg the following formula applies:

$A_{pHX} = ANC_{pHX} * M / N_{pHX}$

With :
A_{pHX} is the ml's of acid needed to reach pH=X for sample of weight M

ANC_{pHX} is the acid neutralization capacity in Mol/kg from table 1 at pH=X.

N_{pHX} is the acid normality selected based on the buffer capacity around pH=X in Mol/l

M is the sample weight in g.

Table A 3.1. ANC/BNC data for a wide range of materials.

Fly ash cement - C1FA		BFS cement - C2FA		Portland Cement	
pH	Mol/kg	pH	Mol/kg	pH	Mol/kg
4	3.824	4	3.890	3.72	3.733
5	3.890	5	3.602	4.8	3.467
6	3.790	6	2.931	6.42	3.333
7	3.561	7	2.878	8.11	3.200
8	3.366	8	2.170	9.77	2.667
9	3.465	9	1.981	10.42	2.333
10	3.238	10	1.746	11.06	1.667
12	1.540	12	0.443	12.46	0.000

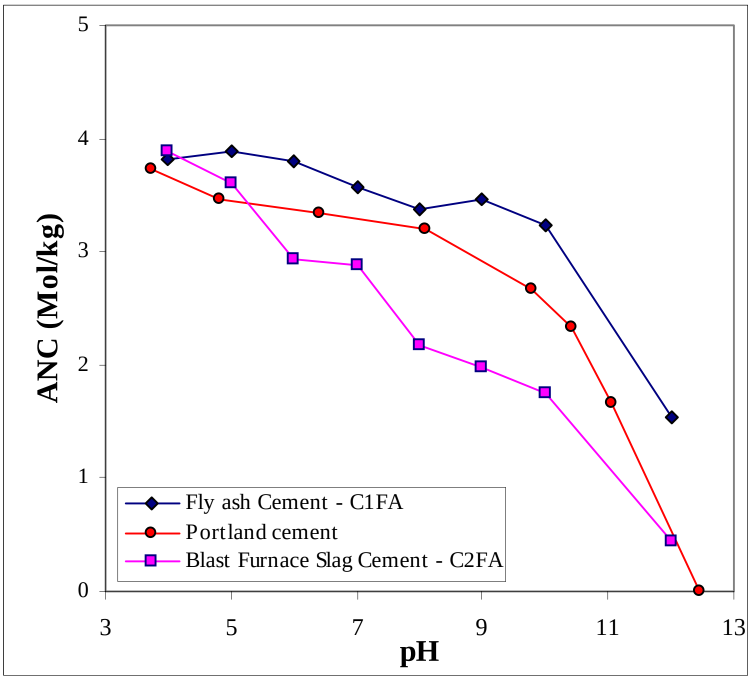


Figure A 3.6. Acid/base neutralization curves for a range of materials (NOTE: The base addition is given as negative values).

ANNEX 4 PHYSICAL CHARACTERIZATION OF TEST CEMENTS.

Sample Code Origin Reference		H1 Holderbank	N1 Norcem	H3 Holderbank	D1 VDZ	H5 Holderbank	H6 Holderbank	H7 Holderbank	N2 Norcem	W1 Weimar	D2 VDZ	W2 Weimar	H9 Holderbank
Date of Mortar Preparation		26-10-98	02-11-98	03-11-98	04-11-98	11-11-98	12-11-98	16-11-98	17-11-98	16-12-98	15-12-98	17-12-98	03-02-99
Cement	[g]	450	450	450	450	450	450	450	450	450	450	450	450
Water	[g]	225	225	225	225	225	225	225	225	225	225	225	225
Sand	[g]	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
W/C ratio		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Curing		95%HR	95%HR	95%HR	95%HR	95%HR	95%HR	95%HR	95%HR	95%HR	95%HR	95%HR	95%HR
Setting time [t1]	min	178	95	136	167	145	103	160	160	80	151	120	150
Setting time [t2]	min	315	146	240	301	245	171	282	245	200	234	290	270
Water demand	%	28.8	23.0	26.0	27.0	25.2	26.0	23.6	23.2	26.4	28.6	20.8	28.6
Soundness	mm	---	---	---	---	---	---	---	---	13.0	---	1.0	---
Mean CS [1 d]	**N/mm²**	**18.3**	**17.3**	**9.7**	**12.3**	**13.6**	**18.6**	**4.4**	**15.0**	**17.0**	**18.1**	**12.6**	**22.4**
Standard dev.	**N/mm²**	**0.37**	**0.08**	**0.10**	**0.35**	**0.08**	**0.17**	**0.41**	**0.39**	**0.14**	**0.35**	**0.42**	**0.39**
Mean CS [2 d]	**N/mm²**	**30.6**	**28,4**	**17.6**	**23.5**	**23.0**	**28.5**	**9.5**	**30.1**	**26.5**	**29.9**	**19.2**	**28.6**
Standard dev.	**N/mm²**	**0.97**	**0.28**	**0.22**	**0.20**	**0.61**	**0.89**	**1.38**	**2.21**	**0.43**	**0.66**	**1.95**	**0.58**
Mean CS [7 d]	**N/mm²**	**43.9**	**43.0**	**34.4**	**35.0**	**33.3**	**41.5**	**22.2**	**44.4**	**37.0**	**39.8**	**36.1**	**50.4**
Standard dev.	**N/mm²**	**2.32**	**0.89**	**0.59**	**0.59**	**0.53**	**0.67**	**1.26**	**0.57**	**0.92**	**0.45**	**1.57**	**0.72**
Mean CS [28 d]	**N/mm²**	**55.6**	**59.4**	**51.9**	**48.1**	**40.0**	**48.6**	**36.1**	**55.7**	**52.8**	**47.4**	**46.0**	**60.7**
Standard dev.	**N/mm²**	**0.95**	**0.23**	**1.43**	**1.84**	**0.51**	**0.77**	**2.17**	**1.23**	**0.89**	**0.59**	**3.40**	**1.32**

ANNEX 5 GRANULOMETRIC CHARACTERISTICS OF TEST CEMENTS

Sample Code Origin Reference		H1 Holderbank	N1 Norcem	H2 Holderbank	H3 Holderbank	H4 Holderbank	H5 Holderbank	H6 Holderbank	 VDZ	D1 VDZ	 VDZ	 VDZ	 VDZ	H7 Holderbank	N2 Norcem	W1 Weimar	D2 VDZ	W2 Weimar	H8 Holderbank	H9 Holderbank
< 192.0 µm	**%**	100.0	100.0	99.6	100.0	100.0	99.9	100	100	99.7	100	100	100	99.9	99.9	99.9	99.7	100	100	100
128.0	**%**	100.0	100.0	99.6	100.0	100.0	99.9	100	100	99.7	100	100	100	99.9	99.9	99.9	99.7	100	100	100
96.0	**%**	100.0	100.0	99.6	100.0	100.0	99.85	100	100	99.7	100	100	100	99.65	99.9	99.9	99.7	100	99.95	100
64.0	**%**	100.0	98.7	95.5	96.1	99.6	92.2	99.25	97.85	98.85	98.65	93.35	100	90.35	95.7	97.15	96.5	94.65	94.55	100
48.0	**%**	100.0	98.1	91.5	96.0	99.2	90.95	98.4	95.75	98	98.15	92.35	100	89.45	95.3	95.9	93.35	92.2	93.85	100
32.0	**%**	94.3	84.4	75.7	79.9	86.6	74.8	87	78.15	85.35	86.05	77.5	98.3	73.65	79.1	84.1	80.35	80.9	76.65	95.5
24.0	**%**	83.9	72.8	66.2	69.1	76.4	64.2	78.3	67.75	75.5	75.25	67.7	95.2	65.35	68.75	76.1	73.1	75.25	65.7	88.15
16.0	**%**	66.2	57.3	50.8	51.1	59.4	52.05	60.6	50.75	58.95	56.95	51.6	84.35	50.65	54.25	64.6	59.3	63	49.45	70.65
12.0	**%**	53.4	48.0	43.5	41.5	48.9	44.85	49.65	41.55	48.15	45.45	42.65	71.9	43.35	45.65	56.1	51.75	56.15	39.95	56.2
8.0	**%**	42.1	38.4	33.7	31.7	37.6	37.05	37.25	30.8	37.5	33.75	32.05	54.35	34.5	35.75	46.65	41.65	46.2	30.05	42.5
6.0	**%**	34.0	31.5	28.3	25.9	30.7	31.2	30.1	25	30.2	26.2	25.65	43.1	29.45	29.45	39.55	35.6	40.3	24.25	34
4.0	**%**	26.8	24.8	20.7	19.8	23.9	25.4	22.4	19	22.65	18.9	19.2	32.85	23.1	23.05	32.65	28	32.7	18.75	26.85
3.0	**%**	21.3	19.6	16.1	16.0	19.4	21.15	17.65	15.9	17.6	14.25	15.35	26.35	19.2	18.85	26.95	22.95	27.55	15.15	21.4
2.0	**%**	16.3	14.0	10.6	11.6	14.8	15.7	12.6	11.85	12.4	10.3	11.3	19.9	14.1	13.75	21.85	16.55	20.5	11.3	16.8
1.5	**%**	11.2	9.7	7.7	8.1	10.3	10.3	8.8	7.9	8.3	7.5	8.05	13.75	9.6	9.25	17.1	12	15.25	7.95	12.1
1.0	**%**	9.1	7.9	6.1	6.4	8.1	8	7.1	5.95	6.65	6.15	6.4	11	7.4	7.3	14.1	9.5	12.05	6.35	9.85
Median Diameter	**µm**	10.8	12.8	15.5	15.5	12.5	14.85	12.1	15.65	12.65	13.6	15.25	7.25	15.55	14	9.4	11.25	9.5	16.25	10.15

ANNEX 6 CHEMICAL COMPOSITION OF TEST CEMENTS

6.1 Major Elements (XRF)

Sample Code		H1	N1	H2	H3	H4	H5	H6		D1				H7	N2	H8	H9	D2	W1	W2
Origin		Holderbank	Norcem	Holderbank	Holderbank	Holderbank	Holderbank	Holderbank	VDZ	VDZ	VDZ	VDZ	VDZ	Holderbank	Norcem	Holderbank	Holderbank	VDZ	Weimar	Weimar
Reference		COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB	COB
SiO_2	%	19.92	21.86	20.90	22.39	20.55	17.71	20.43	19.4	20.5	19.6	18.2	19.9	20.37	19.77	19.15	21.30	20.4	20.64	20.70
Al_2O_3	%	5.07	4.14	4.32	4.22	3.96	5.33	5.10	4.72	4.69	5.38	5.78	5.03	4.54	4.99	5.02	2.81	4.58	4.76	5.15
Fe_2O_3	%	3.33	3.27	3.48	2.87	2.91	2.36	3.04	2.60	2.97	3.23	4.24	2.50	3.75	3.09	3.20	4.63	2.36	2.22	2.45
CaO	%	63.05	63.98	63.17	64.02	62.59	61.48	62.60	61.0	63.2	60.4	63.0	61.0	62.09	62.59	62.15	64.68	63.9	64.33	62.60
Na_2O	%	0.36	0.20	0.14	0.11	0.26	0.13	0.36	0.32	0.20	0.19	0.07	0.34	0.09	0.34	0.21	0.16	0.15	0.08	0.08
K_2O	%	0.80	0.44	0.15	0.33	0.80	1.14	0.61	0.97	0.82	1.53	0.78	0.79	0.27	0.77	0.60	0.48	1.37	0.12	0.13
MgO	%	0.76	1.60	3.50	1.67	2.27	3.00	2.63	3.26	2.03	2.50	0.95	3.69	0.89	2.54	2.79	0.60	3.47	3.44	3.41
SO_3	%	3.32	2.70	2.59	1.87	3.13	2.60	2.54	3.23	2.53	3.07	2.65	3.77	2.63	2.94	2.60	2.88	2.83	2.75	2.81
Mn_2O_3	%	0.09	0.07	0.08	0.12	0.09	0.07	0.24	0.16	0.13	0.09	0.62	0.11	0.06	0.08	0.11	0.07	0.06	0.05	0.07
TiO_2	%	0.34	0.23	0.24	0.42	0.20	0.28	0.24	0.24	0.27	0.28	0.28	0.24	0.73	0.27	0.27	0.15	0.22	0.22	0.24
P_2O_5	%	0.49	0.06	0.10	0.07	0.13	0.05	0.07	0.15	0.07	0.09	0.12	0.09	0.04	0.09	0.15	0.15	0.06	0.06	0.06
Cl	%	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00
LoI	%	2.14	1.17	1.24	2.07	2.79	5.99	1.51	3.10	2.55	3.21	3.03	1.63	4.53	2.52	3.36	1.74	0.61	0.65	0.57
Total	%	99.68	99.72	99.90	100.13	99.67	100.12	99.36	99.2	100	99.5	99.7	99.0	99.96	99.97	99.59	99.65	99.9	99.30	98.25
Cl *	%	0.039	0.012	0.003	0.003	0.005	0.015	0.014	0.052	0.018	0.049	0.005	0.007	0.010	0.015	0.021	0.024	0.033	0.005	0.002
CaO free	%	1.73	0.78	0.61	1.77	0.67	3.22	2.21	1.25	1.46	2.46	1.75	1.34	2.45	0.52	1.74	2.61	1.77	5.98	2.27

* potentiometric

6.2 Trace Elements (ICP, AAS)

Sample Code		H1	N1	H2	H3	H4	H5	H6		D1				H7	N2	H9	D2	W1	W2
Origin		Holderbank	Norcem	Holderbank	Holderbank	Holderbank	Holderbank	Holderbank	VDZ	VDZ	VDZ	VDZ	VDZ	Holderbank	Norcem	Holderbank	VDZ	Weimar	Weimar
Reference		VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ	VDZ
As	ppm	7.2	23	23	2.3	1.8	3.6	5.7	22	8.6	28	11.8	3.6	10.2	4.5	4.9	6.9	102	338
Ba	ppm															201			
Be	ppm	0.86	0.8	0.46	1.1	1.4	1.7	2.7	1.3	1.6	1.6	2.5	1.0	0.95	0.81	0.74	0.53	0.84	0.94
Cd	ppm	0.96	0.21	0.25	0.15	0.22	0.17	0.57	0.58	0.61	0.73	1.5	0.18	0.51	0.38	0.94	< 0.10	0.32	1.2
Co	ppm	12.8	12	4.7	14	8.7	6.3	22	12.3	7.3	9.5	9.6	10.3	7.6	8.9	5.9	7.5	6.5	14.4
Cr tot.	ppm	89	184	31	92	95	44	578	44	76	58	46	81	129	70	33	29	335	1396
Cr 6+	ppm	10	12	< 1	6	9	8	94	6	10	7	7	9	2	16	3	6	7	39
Cu	ppm	54	16	24	16	18	18	27	28	16	27	27	25	16.3	14	15.4	29	23	22
Hg	ppm	< 0,02	< 0,02	< 0,02	< 0,02	< 0,02	< 0,02	< 0,02	< 0,02	<0,02	< 0,02	< 0,02	< 0,02	<0,02	0.03	0.12	< 0.02	0.03	0.08
Mn	ppm	508.0	379	421	676	597	431	1863	991	825	512	3901	674	329	364	298	218	200	229
Mo	ppm	3.7	1.9	1.9	< 1,00	< 1,00	< 1,00	< 1,00	8.4	6.9	3.8	6.2	2.0	< 1,00	5	4.3	1.1	46	202
Ni	ppm	47	61	25	25	33	50	75	41	45	38	62	71	42	22	13.9	14	14	42
Pb	ppm	64	20	12	12	4.9	20	19	32	106	44	36	1.5	5.8	30	57	15	50	13
Sb	ppm	4.8	2.1	< 1,00	< 1,00	1.2	< 1,00	< 1,00	2.8	1.2	2.6	2.9	0.49	< 1,00	< 1,00	3.9	3.6	7.8	31
Se	ppm																		
Sn	ppm	13.6	< 1,00	1.6	< 1,00	4.1	2.3	< 1,00	2.0	< 1,00	2.8	6.4	< 1,00	2.4	< 1,00	3.6	4.8	< 1,00	3.4
Sr	ppm																		
Te	ppm																		
Tl	ppm	< 0.50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	1.1	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 1	< 1.00	0.26	0.46
V	ppm	100	44	139	73	15	228	36	40	31	53	122	102	34	30	27	22	25	27
Zn	ppm	382	55	27	33	430	48	83	100	104	384	176	183	30	43	223	130	502	2027

ANNEX 7 1. Leaching Test data: NEN 7341 (µg/L of leachate)

Origin Reference		**H1** **983129**	**N1** **983003**	**H3** **983053**	**H4** **983257**	**H5** **983258**	**H6** **983261**	**D1** **983293**	**H7** **983308**	**N2** **983309**	**W1** **983570**	**D2** **983571**	**W2** **983572**	**H9** **990013**
pH 1 min	**Detection**	12.32	12.67	12.34	12.49	12.32	12.31	12.81	12.32	12.41	12.78	12.65	12.72	12.89
pH 10 min	**limit**	12.49	12.74	12.48	12.67	12.40	12.46	13.03	12.39	12.58	12.88	12.80	12.85	13.46
Al µg/L	<50	3547	1634	1753	2464	4493	2667	2752	2141	3552	3848	3977	4675	1554
As µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	13	<2	29	<2
Ba µg/L	<2	548	208	448	518	251	451	389	224	563	277	296	361	430
Be µg/L	<1	1.1	<1	1.2	<1	<1	1.3	1.5	<1	<1	1.3	1.0	1.4	1.2
Ca µg/L	<25	806000	873800	909600	992000	968700	824600	802600	1005000	913000	805100	1011000	942000	1175000
Cd µg/L	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
Cl µg/L	<1000	2127	1773	1418	1773	2127	1773	3191	2127	1773	3191	3900	2836	2482
Co µg/L	<10	19	21	19	13	11	32	15	7	15	15	23	15	20
Cr µg/L	<10	111	230	139	61	<10	597	47	138	73	492	<10	2008	44
Cu µg/L	<10	41	<10	<10	16	16	<10	12	<10	21	24	29	28	15
Fe µg/L	<10	32	115	38	1974	5209	2729	2830	2904	4660	3917	2168	4742	109
Hg µg/L	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
K µg/L	<1500	17670	9501	10840	16090	22980	18950	16400	6364	17190	4618	26820	4769	10580
Mg µg/L	<5	7805	13970	16030	23470	28870	26420	19670	7330	25750	38110	36320	33860	6825
Mn µg/L	<10	445	424	262	641	522	2066	1131	338	531	467	386	444	414
Mo µg/L	<5	11.9	<5	<5	<5	<5	<5	<5	<5	<5	74	<5	338	<5
Na µg/L	<200	6352	2426	374	2471	717	5144	3028	547	3100	1600	2620	1522	2906
Ni µg/L	<10	80	79	39	65	90	135	68	37	71	50	43	57	28
P µg/L	<25	307	72	86	90	54	52	64	62	53	39	47	37	87
Pb µg/L	<1	<1	<1	<1	<1	3	<1	5	<1	<1	<1	<1	<1	<1
S µg/L	<250	27878	23906	18138	29035	21927	21980	20350	23813	23142	21971	24783	22212	22640
Sb µg/L	<2	4	<2	<2	<2	<2	<2	<2	<2	<2	10	<2	21	<2
Si µg/L	<125	43660	47910	49270	43400	38970	41280	43590	46080	38760	52050	45700	52260	45800
Sn µg/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr µg/L	<1	2283	1077	485	1812	796	747	581	1127	1496	2383	2534	2417	2066
Ti µg/L	<5	18	18	19	46	16	34	16	22	17	40	35	37	12
Tl µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
V µg/L	<1	44	10	22	<1	30	3	2	6	3	9	<1	2	<1
Zn µg/L	<2	685	24	<2	483	32	79	124	<2	21	1111	143	4136	423
Vol.Acide ajouté ml	15.1	18.1	16.3	18.5	18.2	18.0	18.3	17.7	17.6	18.0	20.1	19.4	19.0	18.6
Poids d'échantillon g	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Facteur	103.774	104.531	104.075	104.613	104.544	104.500	104.569	104.419	104.394	104.494	105.013	104.838	104.744	104.744

Leaching Test data: NEN 7341 (mg/kg leached).

Origin Reference		H1 983129	N1 983003	H3 983053	H4 983257	H5 983258	H6 983261	D1 983293	H7 983308	N2 983309	W1 983570	D2 983571	W2 983572	H9 990013
pH 1 min	**Detection**	12.32	12.67	12.34	12.49	12.32	12.31	12.81	12.32	12.41	12.78	12.65	12,72	12,89
pH 10 min	**limit**	12.49	12.74	12.48	12.67	12.40	12.46	13.03	12.39	12.58	12.88	12.80	12,85	13,13
Al mg/kg	<5	371	170	183	258	470	279	287	224	371	404	417	490	163
As mg/kg	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	1.4	<0,2	3,0	<0,2
Ba mg/kg	<0,2	57	22	47	54	26	47	41	23	59	29	31	38	45
Be mg/kg	<0,1	0.1	<0,1	0.1	<0,1	<0,1	0.1	0.2	<0,1	<0,1	0.1	0.1	0,1	0,1
Ca mg/kg	<2,5	84252	90941	95156	103707	101229	86227	83806	104916	95403	84546	105991	98669	123074
Cd mg/kg	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05	<0,05
Cl mg/kg	<100	222	184	148	185	222	185	333	222	185	335	409	297	260
Co mg/kg	<1	2.0	2.2	2.0	1.0	1.0	3.3	1.5	1.0	1.5	1.6	2.4	1,6	2,1
Cr mg/kg	<1	12	24	15	6.4	<1	62	4.9	14	7.6	52	<1	210	4,6
Cu mg/kg	<1	4.3	<1	<1	1.7	1.6	<1	1.2	<1	2.2	2.5	3.0	2,9	1,6
Fe mg/kg	<1	3.3	12	3.9	206	544	285	296	303	487	411	227	497	11
Hg mg/kg	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01
K mg/kg	<150	1847	989	1134	1682	2401	1982	1712	664	1796	485	2812	500	1108
Mg mg/kg	<0,5	816	1454	1677	2454	3017	2763	2054	765	2691	4002	3808	3547	715
Mn mg/kg	<1	46	44	27	67	55	216	118	35	56	49	40	47	43
Mo mg/kg	<0,5	1.2	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	8	<0,5	35	<0,5
Na mg/kg	<20	664	252	39	258	75	538	316	57	324	168	275	159	304
Ni mg/kg	<1	8.3	8.3	4.1	6.8	9.4	14.1	7.1	3.8	7.4	5.3	4.5	6,0	2,9
P mg/kg	<2,5	32	7.5	9.0	9.4	5.6	5.4	6.7	6.5	5.5	4.1	4.9	3,9	9,1
Pb mg/kg	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
S mg/kg	<25	2914	2488	1897	3035	2291	2298	2125	2486	2418	2307	2598	2327	2371
Sb mg/kg	<0,2	0.42	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	<0,2	1.05	<0,2	2,20	<0,2
Si mg/kg	<12,5	4564	4986	5154	4537	4072	4317	4552	4810	4050	5466	4791	5474	4797
Sn mg/kg	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5	<0,5
Sr mg/kg	<0,1	239	112	51	189	83	78	61	118	156	250	266	253	216
Ti mg/kg	<0,5	1.9	1.9	2.0	4.8	1.7	3.6	1.7	2.3	1.8	4.2	3.7	3,9	1,3
Tl mg/kg	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
V mg/kg	<0,1	4.6	1.0	2.3	<0,1	3.1	0.3	0.2	0.6	0.3	0.9	<0,1	0,2	<0,1
Zn mg/kg	<0,2	72	2.5	<0,2	50	3.3	8.3	13	<0,2	2.2	117	15	433	44

ANNEX 7.2 pH Dependence leaching test data

PH STAT DATA

15	Gram			Li	B	Na	Mg	Al	Si	P	S	K	Ca	Ti
150	ml	10 mol		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Code	pH	ml acid	L/S	0.001	0.003	0.009	0.000	0.000	0.049	0.003	0.039	0.013	0.022	0.002
H1-1	12.26	0.0	10.00	0.263	0.002	56.437	0.009	0.062	0.53	0.008	2.493	124.7	754	-0.001
H1-2	11.05	2.5	10.17	0.360	0.003	59.137	0.707	0.050	7.72	0.035	27.856	131.4	4495	-0.007
H1-3	10.39	3.4	10.23	0.398	0.178	61.169	4.738	0.047	17.40	0.116	252.6	128.3	6289	-0.009
H1-4	7.92	4.5	10.30	0.505	0.565	66.859	62.298	0.002	41.40	0.134	271.5	125.8	8127	-0.010
H1-5	5.60	5.0	10.33	0.544	1.036	68.734	73.619	0.581	33.19	0.141	306.2	132.2	8841	-0.012
H1-6	3.85	5.5	10.37	0.581	1.316	70.573	86.711	154.7	109.80	0.142	300.7	149.9	9220	-0.008
H1-7	3.24	6.0	10.40	0.599	1.803	73.836	90.363	412.4	469.14	1.545	300.7	159.7	9373	1.538
N1-1	12.28	0.0	10.00	0.147	0.023	29.665	0.371	1.405	2.72	0.006	2.6	74.7	903	0.000
N1-2	10.94	3.0	10.20	0.209	0.008	31.227	1.011	0.213	9.17	0.034	90.8	77.7	5418	-0.007
N1-3	10.23	4.0	10.27	0.256	0.075	33.330	9.974	0.023	18.87	0.079	230.2	73.7	7253	-0.013
N1-4	9.34	5.0	10.33	0.262	0.092	33.139	76.7	0.214	28.98	0.100	233.4	69.0	7822	-0.012
N1-5	3.93	5.7	10.38	0.381	0.650	36.356	188.5	44.8	170.78	0.098	254.1	80.6	9426	-0.009
N1-6	3.20	6.2	10.41	0.392	1.570	39.214	198.7	320.7	540.97	0.542	252.1	87.0	9752	2.143
N1-7	2.40	6.5	10.43	0.380	1.510	34.787	196.0	454.9	1871	3.818	231.6	85.7	9550	12.588
N1-8	8.45	4.5	10.30	0.294	0.125	33.719	107.9	0.438	44.98	0.090	232.6	72.6	8291	0.002
H3-1	12.24	0.0	10.00	0.077	0.017	11.508	1.2	2.742	10.75	0.013	2.5	44.2	976	0.043
H3-2	10.98	2.7	10.18	0.122	0.005	12.859	0.906	0.179	9.50	0.015	40.3	50.4	5015	-0.007
H3-3	10.35	3.5	10.23	0.158	0.100	13.852	4.470	0.064	20.50	0.058	147.4	51.7	6732	-0.009
H3-4	9.13	4.5	10.30	0.208	0.156	14.637	95.6	0.010	36.51	0.062	157.6	49.6	7957	-0.012
H3-5	6.67	5.5	10.37	0.294	0.542	15.778	175.4	0.266	52.65	0.113	173.2	52.5	8969	0.018
H3-6	3.52	6.0	10.40	0.319	0.919	16.416	203.2	214.5	266.33	0.092	173.2	65.5	9750	0.199
H3-7	2.88	6.5	10.43	0.335	1.679	16.923	209.6	413.4	931.42	1.983	168.7	69.5	10033	9.830
H3-8	8.68	5.0	10.33	0.184	0.133	13.989	79.5	0.674	37.46	0.072	155.0	65.0	7773	-0.004
D1-1	12.46	0.0	10.00	0.133	0.006	29.555	0.051	0.176	1.14	0.003	0.9	148.7	832	0.000
D1-2	11.06	2.5	10.17	0.180	0.010	31.361	0.705	0.090	8.37	0.012	27.1	146.8	4470	-0.006
D1-3	10.42	3.5	10.23	0.226	0.196	32.400	5.779	0.050	18.15	0.065	188.7	137.0	6412	-0.009
D1-4	9.77	4.0	10.27	0.293	0.233	34.462	64.0	0.011	21.97	0.069	197.0	134.2	7273	-0.011
D1-5	8.11	4.8	10.32	0.389	0.545	35.325	190.2	0.009	43.41	0.076	210.3	130.4	8504	-0.013
D1-6	6.42	5.0	10.33	0.402	0.996	35.079	206.9	1.856	82.76	0.117	213.4	130.3	8608	0.065
D1-7	4.80	5.2	10.35	0.422	1.152	35.837	220.3	6.076	165.40	0.074	217.9	138.6	8890	-0.011
D1-8	3.72	5.6	10.37	0.448	1.331	37.072	245.6	210.9	216.12	0.071	222.8	153.5	9633	0.001

PH STAT DATA

15	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Mo	Cd
150	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Code	0.002	0.003	0.000	0.002	0.003	0.006	0.001	0.001	0.010	0.015	0.000	0.009	0.001
H1-1	-0.001	0.052	0.000	0.031	0.007	0.001	0.000	0.015	-0.001	0.001	11.991	0.009	0.000
H1-2	0.010	0.628	0.000	0.053	0.004	-0.001	-0.001	0.000	-0.007	0.000	18.196	0.099	0.000
H1-3	0.067	1.033	0.000	0.015	0.000	-0.001	-0.003	0.001	0.007	-0.008	20.573	0.112	0.000
H1-4	0.052	0.915	1.075	0.004	0.027	0.972	-0.003	0.003	0.001	0.000	24.132	0.074	0.001
H1-5	0.009	0.810	4.367	0.004	0.154	3.126	0.043	3.047	-0.004	-0.002	26.116	0.044	0.008
H1-6	0.003	0.553	7.703	0.663	0.210	5.777	0.865	5.745	-0.012	0.003	27.274	0.007	0.014
H1-7	0.091	1.098	10.157	42.264	0.269	11.894	1.301	6.420	0.007	0.007	27.679	0.005	0.015
N1-1	0.000	0.055	0.022	0.036	0.007	0.015	0.008	0.304	-0.001	-0.009	6.203	-0.003	0.009
N1-2	0.005	1.613	0.004	0.036	0.007	0.002	-0.003	0.006	-0.007	0.005	9.460	0.012	0.000
N1-3	0.032	2.105	0.000	0.001	-0.002	-0.007	-0.011	0.001	-0.025	-0.005	10.848	0.007	-0.002
N1-4	0.080	2.189	0.001	0.001	0.006	0.008	-0.006	0.001	0.002	0.010	11.204	0.016	0.001
N1-5	0.004	1.324	6.561	0.334	0.200	5.148	0.203	0.707	0.000	0.018	13.033	0.000	0.004
N1-6	0.075	2.018	8.531	66.7	0.279	17.841	0.387	0.864	0.023	0.012	13.359	-0.001	0.003
N1-7	0.399	3.662	8.753	408.4	0.282	18.232	0.391	0.799	0.132	-0.015	12.926	-0.003	0.004
N1-8	0.071	2.094	0.046	0.365	-0.001	0.129	-0.005	0.001	0.004	0.011	11.410	0.009	0.000
H3-1	0.002	0.053	0.055	1.804	0.006	0.125	0.000	0.014	0.012	0.007	2.835	0.001	0.001
H3-2	0.007	0.745	0.001	0.025	-0.004	-0.002	-0.006	-0.002	-0.007	-0.014	4.106	0.000	0.000
H3-3	0.050	1.076	0.000	0.009	0.004	0.000	-0.007	-0.001	0.005	0.003	4.424	0.006	0.001
H3-4	0.121	1.205	0.001	0.005	-0.003	0.008	-0.008	-0.001	0.000	0.012	4.806	0.003	0.001
H3-5	0.021	1.215	1.907	0.209	0.134	2.141	-0.008	0.012	-0.006	0.003	5.220	0.002	0.000
H3-6	0.011	1.127	7.211	3.245	0.263	5.787	0.318	0.304	0.024	0.020	5.427	0.008	0.003
H3-7	0.537	1.948	14.276	154.6	0.320	17.954	0.353	0.369	-0.094	-0.018	5.557	-0.013	-0.001
H3-8	0.124	1.242	0.031	0.109	0.003	0.063	-0.006	0.004	0.005	0.011	4.714	0.003	0.000
D1-1	0.000	0.025	0.000	0.011	-0.001	-0.002	0.001	0.002	-0.003	-0.003	3.502	0.001	0.000
D1-2	0.004	0.508	0.000	0.006	0.002	-0.001	-0.003	-0.001	0.007	0.002	5.064	0.006	0.000
D1-3	0.019	0.814	0.000	0.005	-0.002	-0.001	-0.006	0.000	-0.007	0.006	5.808	0.004	-0.001
D1-4	0.031	0.849	0.000	0.003	-0.005	-0.003	-0.008	-0.001	-0.004	0.005	6.291	0.006	0.000
D1-5	0.015	0.848	0.610	0.004	0.026	0.889	-0.007	0.001	0.002	0.002	6.947	-0.001	0.001
D1-6	0.008	0.816	3.256	0.737	0.112	3.663	-0.006	0.413	-0.004	0.008	7.012	0.006	0.004
D1-7	0.003	0.785	4.628	0.034	0.125	4.978	0.079	1.197	-0.011	0.003	7.268	0.000	0.006
D1-8	0.001	0.762	6.218	1.065	0.171	6.136	0.257	1.610	-0.016	0.003	7.626	0.004	0.007

ANNEX 7.2 pH DEPENDENCE LEACHING TEST DATA

PH STAT DATA

15	Sn	Sb	Ba	Pb	As hydr	Sb hydr	Se hydr	Tl	Be
150	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
DTL	0.008	0.013	0.000	0.065	0.0003	0.0012	0.0007	0.014	0.0003
H1-1	0.002	-0.001	2.019	0.053					
H1-2	-0.002	0.003	2.252	-0.025					
H1-3	0.003	0.002	1.457	-0.017					
H1-4	0.004	0.002	1.352	-0.005					
H1-5	0.003	0.012	1.337	-0.012					
H1-6	0.001	-0.005	1.582	0.404					
H1-7	0.015	0.016	1.488	0.541					
N1-1	-0.006	0.001	0.682	0.004					
N1-2	0.003	0.002	0.947	-0.005					
N1-3	-0.005	-0.015	0.807	-0.015					
N1-4	0.001	0.003	0.937	-0.005					
N1-5	0.009	-0.002	2.109	0.005					
N1-6	0.001	0.005	2.200	0.221					
N1-7	-0.013	0.024	2.262	0.354					
N1-8	-0.002	0.009	1.016	0.026					
H3-1	0.004	0.004	1.180	0.013					
H3-2	-0.004	-0.017	1.763	0.005					
H3-3	0.003	0.005	1.710	-0.023					
H3-4	0.003	0.010	1.858	0.034					
H3-5	0.000	-0.010	2.776	-0.035					
H3-6	0.007	0.021	2.685	0.042					
H3-7	-0.027	-0.062	2.977	0.050					
H3-8	-0.002	0.000	2.240	0.005					
D1-1	-0.001	-0.003	1.431	0.004					
D1-2	-0.002	0.001	1.704	0.000					
D1-3	0.000	-0.006	1.150	0.001					
D1-4	-0.001	-0.009	1.182	0.045					
D1-5	-0.005	-0.001	1.587	-0.009					
D1-6	-0.002	-0.001	1.846	0.030					
D1-7	-0.003	0.006	1.825	0.061					
D1-8	0.002	0.009	1.731	0.329					

ANNEX 7.2 pH DEPENDENCE LEACHING TEST DATA

PH STAT DATA

15				Li	B	Na	Mg	Al	Si	P	S	K	Ca	Ti
150		10 mol		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	pH	ml acid												
H5-1	12.35	0.0	10.00	0.088	0.011	17.812	0.160	0.385	1.36	0.003	0.7	195.8	842	-0.001
H5-2	11.11	2.5	10.17	0.111	0.008	18.776	0.540	0.265	6.80	0.012	4.9	208.3	4116	-0.005
H5-3	10.36	3.5	10.23	0.165	0.272	19.436	8.4	0.103	13.70	0.070	200.6	199.7	6196	-0.010
H5-4	8.40	4.5	10.30	0.396	0.749	20.543	271.1	0.004	25.81	0.094	214.6	189.3	7529	-0.012
H5-5	7.00	4.8	10.32	0.418	1.256	20.889	298.4	0.057	43.26	0.098	224.9	192.5	8082	-0.009
H5-6	5.90	5.0	10.33	0.453	1.880	21.497	311.4	0.492	80.88	0.111	228.0	195.8	8285	0.014
H5-7	5.24	5.2	10.35	0.471	2.002	22.109	325.3	1.332	98.53	0.094	236.2	204.6	8682	-0.011
H5-8	3.66	5.6	10.37	0.465	2.254	21.146	343.2	249.45	183.70	0.093	232.6	211.8	8896	-0.002
H6-1	12.33	0.0	10.00	0.140	0.017	55.395	0.928	1.203	1.71	0.004	1.54	140.1	859	-0.002
H6-2	11.23	2.5	10.17	0.189	0.007	58.135	0.394	0.607	4.97	0.003	1.80	149.4	4324	-0.007
H6-3	10.11	4.0	10.27	0.293	0.247	62.505	17.443	0.066	15.52	0.078	205.79	141.0	7158	-0.008
H6-4	9.34	4.5	10.30	0.351	0.323	62.728	142.9	0.014	28.84	0.083	215.30	131.5	8044	-0.011
H6-5	8.36	5.0	10.33	0.498	0.528	64.758	251.6	0.012	40.73	0.089	219.49	130.6	8596	-0.012
H6-6	6.78	5.2	10.35	0.512	0.952	64.033	276.3	0.021	34.80	0.102	226.70	131.0	8872	-0.013
H6-7	4.22	5.7	10.38	0.529	1.232	64.431	297.9	30.2	112.84	0.076	225.29	144.6	8913	-0.011
H6-8	3.53	6.5	10.43	0.538	1.319	64.801	311.0	279.6	231.55	0.079	224.99	151.1	9050	0.031
N2-1	12.58	0.0	10.00	0.111	-0.001	46.188	0.0	0.229	0.72	0.005	1.10	123.2	838	-0.001
N2-2	11.27	2.5	10.17	0.165	0.006	50.328	0.5	0.227	5.81	0.006	3.75	134.3	4295	-0.008
N2-3	10.59	3.5	10.23	0.187	0.186	48.798	3.3	0.076	15.33	0.084	243.76	123.5	6158	-0.011
N2-4	9.30	4.3	10.29	0.313	0.318	50.992	154.9	0.009	33.34	0.093	252.98	114.2	7334	-0.014
N2-5	8.31	4.8	10.32	0.403	0.501	53.569	227.7	0.010	40.64	0.093	253.85	114.9	8039	-0.013
N2-6	6.47	5.0	10.33	0.442	0.993	55.889	256.1	0.753	68.65	0.131	263.21	118.1	8396	0.037
N2-7	4.89	5.2	10.35	0.463	1.466	57.556	274.2	4.617	165.29	0.090	265.58	125.5	8672	-0.012
N2-8	4.26	5.5	10.37	0.486	1.518	60.259	288.9	32.463	212.53	0.078	274.35	134.5	9055	-0.013
H7-1	12.18	0.0	10.00	0.089	0.014	10.696	0.298	0.161	1.15	0.004	1.20	36.3	839	-0.002
H7-2	10.87	2.5	10.17	0.111	0.005	11.673	0.876	0.050	12.78	0.046	145.85	38.7	4502	-0.008
H7-3	9.86	3.5	10.23	0.149	0.105	13.022	19.254	0.008	30.76	0.071	210.01	37.4	6360	-0.011
H7-4	8.70	4.0	10.27	0.180	0.151	13.696	55.583	0.004	45.47	0.071	215.08	37.4	7124	-0.014
H7-5	7.00	4.5	10.30	0.212	0.327	14.457	72.056	0.063	57.13	0.086	231	39.2	7997	-0.006
H7-6	5.51	4.8	10.32	0.242	0.566	15.452	84.208	1.046	136.64	0.212	240	41.4	8426	0.103
H7-7	4.26	5.0	10.33	0.263	0.650	15.753	89.398	14.2	242.93	0.079	244	45.8	8776	-0.009
H7-8	3.93	5.2	10.35	0.27	0.74	15.9	93.03	75.3	257.01	0.075	241	46.9	8763	-0.006

PH STAT DATA

15	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Mo	Cd
150	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
H5-1	0.001	0.010	0.004	0.006	0.003	0.004	0.003	0.005	0.001	0.000	4.413	0.001	0.001
H5-2	0.019	0.158	0.000	0.003	0.004	0.001	-0.002	0.001	0.003	0.006	5.933	0.016	0.001
H5-3	0.192	0.237	0.000	0.005	-0.006	0.000	-0.006	-0.001	-0.010	0.002	6.732	0.013	0.000
H5-4	0.241	0.021	0.480	0.000	0.016	2.452	-0.008	0.000	-0.018	0.005	7.398	0.012	0.000
H5-5	0.126	0.012	2.793	0.027	0.094	7.977	-0.008	0.010	-0.011	0.003	7.660	0.008	0.000
H5-6	0.078	0.005	5.267	0.201	0.165	14.021	-0.006	0.249	-0.003	0.005	7.823	0.006	0.002
H5-7	0.053	0.007	5.992	2.809	0.182	16.559	0.017	0.354	-0.017	0.009	8.104	0.005	0.001
H5-8	0.020	0.216	7.891	16.016	0.221	20.399	0.212	0.514	-0.017	0.014	8.152	0.003	0.001
H6-1	0.000	0.164	0.025	0.020	0.006	0.038	-0.001	0.007	-0.002	0.012	4.819	0.000	0.000
H6-2	-0.001	2.492	0.002	0.004	-0.002	0.003	-0.004	-0.001	-0.004	-0.007	7.038	0.004	0.000
H6-3	0.025	6.624	0.001	0.003	0.002	0.005	-0.009	-0.002	0.006	0.012	7.975	0.009	0.001
H6-4	0.045	6.868	0.002	0.004	0.002	0.012	-0.012	0.000	0.010	0.011	8.226	0.006	0.001
H6-5	0.028	6.440	1.589	0.003	0.019	0.927	-0.008	-0.002	-0.021	0.010	8.601	0.002	0.000
H6-6	0.003	6.128	8.356	0.011	0.157	3.497	-0.008	0.063	-0.021	0.012	8.829	-0.002	0.001
H6-7	-0.001	5.920	13.056	0.110	0.267	5.142	0.171	0.895	-0.002	0.008	9.060	0.003	0.004
H6-8	-0.001	5.948	15.893	1.888	0.312	5.678	0.366	1.107	-0.010	0.012	9.130	-0.003	0.003
N2-1	0.000	0.022	0.000	0.021	0.004	-0.001	0.002	0.002	-0.001	0.002	7.276	-0.004	0.000
N2-2	0.004	0.339	0.000	0.050	0.011	-0.004	0.000	-0.001	-0.006	0.002	11.081	0.011	0.000
N2-3	0.021	0.829	0.000	0.008	0.005	0.002	-0.004	0.000	-0.001	0.008	11.776	0.012	0.001
N2-4	0.070	0.814	0.002	0.002	-0.004	0.017	-0.005	-0.001	-0.004	0.008	12.918	0.014	0.000
N2-5	0.026	0.700	1.224	0.010	0.024	0.781	-0.007	-0.002	-0.018	0.008	13.762	0.009	0.000
N2-6	0.011	0.611	4.819	0.553	0.122	4.041	-0.002	0.130	-0.015	0.008	14.370	0.002	0.001
N2-7	0.007	0.331	6.588	0.028	0.185	9.263	0.074	0.473	-0.018	0.009	14.928	0.004	0.001
N2-8	0.005	0.325	7.256	0.096	0.199	9.381	0.150	0.553	-0.031	0.010	15.619	0.001	0.001
H7-1	0.001	0.041	0.007	0.003	-0.002	0.003	-0.002	0.002	-0.003	0.002	4.550	-0.002	0.001
H7-2	0.014	1.016	0.001	0.002	-0.006	-0.007	-0.003	-0.001	-0.012	0.009	6.486	0.005	0.000
H7-3	0.092	1.328	0.001	0.001	-0.003	-0.008	-0.006	-0.001	-0.017	0.008	8.115	0.006	0.001
H7-4	0.085	1.317	0.003	0.001	0.001	0.074	-0.008	-0.001	-0.007	0.016	8.901	0.010	0.000
H7-5	0.022	1.320	1.124	0.031	0.045	1.092	-0.007	0.010	-0.022	0.013	9.726	0.006	0.000
H7-6	0.011	1.168	3.016	0.578	0.088	3.568	0.006	0.305	-0.020	0.000	10.332	0.007	0.005
H7-7	0.009	1.090	3.615	0.112	0.103	4.506	0.139	0.401	-0.022	0.006	10.847	0.006	0.005
H7-8	0.005	0.70	4.481	0.360	0.118	5.623	0.193	0.424	-0.006	0.010	10.843	0.004	0.005

PH STAT DATA

15	Sn	Sb	Ba	Pb	As hydr	Sb hydr	Se hydr	Tl	Be
150	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
H5-1	0.000	0.010	0.781	-0.021					
H5-2	0.001	0.006	1.099	-0.010					
H5-3	-0.003	0.007	0.763	0.029					
H5-4	0.001	-0.006	1.033	-0.017					
H5-5	0.003	-0.007	1.397	-0.013					
H5-6	-0.002	-0.002	1.794	0.010					
H5-7	-0.004	-0.003	1.958	-0.015					
H5-8	-0.005	0.003	2.312	0.015					
H6-1	-0.001	0.001	1.557	-0.004	0.0003	0.0008	0.0001	-0.019	0.0003
H6-2	-0.007	-0.013	2.574	-0.057	0	0.0001	0	-0.014	0.0001
H6-3	0.003	0.012	1.414	-0.006	0.0005	0.0005	0.0005	0.015	0.0003
H6-4	0.004	0.017	1.414	0.017	0.0013	0.0002	0.0004	0.005	0.0001
H6-5	0.000	-0.009	1.627	0.000	0.0017	0.0002	0.0002	-0.006	0.0001
H6-6	-0.001	-0.009	1.657	0.015	0.0002	0.0007	0	-0.02	0.0001
H6-7	-0.004	-0.007	1.644	0.016	0.0003	0.0003	0.0001	-0.043	0.0058
H6-8	-0.001	0.007	1.671	0.041	0	0.0003	0.0001	-0.028	0.0137
N2-1	-0.001	-0.007	1.091	-0.015	0	0.0001	-0.0001	-0.014	0.0002
N2-2	-0.002	0.007	1.727	-0.015	0	0.0001	-0.0002	-0.006	-0.0001
N2-3	-0.003	-0.008	0.977	0.001	0.0006	-0.0002	-0.0001	0.036	0.0001
N2-4	0.001	-0.006	1.161	-0.006	0.0015	-0.0001	0	0	0.0001
N2-5	-0.003	-0.003	1.360	-0.023	0.001	0.0002	-0.0002	0.022	0.0001
N2-6	0.002	0.011	1.768	0.010	0.001	-0.0001	0	-0.038	-0.0006
N2-7	0.003	-0.006	1.774	0.014	0	-0.0002	-0.0002	-0.03	0.0024
N2-8	0.009	-0.013	1.777	0.006	-0.0001	-0.0007	-0.0002	-0.015	0.0071
H7-1	0.001	0.000	0.567	0.021					
H7-2	0.005	-0.003	0.542	-0.030					
H7-3	0.002	-0.008	0.506	-0.011					
H7-4	-0.002	-0.011	0.642	0.008					
H7-5	0.004	0.000	1.118	-0.030					
H7-6	0.002	-0.001	1.573	0.010					
H7-7	-0.001	0.002	1.875	0.011					
H7-8	0.001	-0.005	1.97	0.007					

ANNEX 7.2 pH DEPENDENCE LEACHING TEST DATA

PH STAT DATA

15				Li	B	Na	Mg	Al	Si	P	S	K	Ca	Ti
150		10 mol		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
	pH	ml acid												
W1-1	12.56	0	10.00	0.06	0.00	11.3	0.00	0.186	0.47	0.015	1.0	17.0	904	0.008
W1-2	11.4	2.5	10.17	0.08	0.01	12.0	0.26	0.658	3.43	0.008	1.3	17.3	4459	0.001
W1-3	10.9	3.5	10.23	0.11	0.24	12.5	1.16	0.252	8.88	0.084	203	16.9	6302	-0.003
W1-4	9.94	4.3	10.29	0.16	0.32	13.2	46.87	0.030	14.76	0.083	227	16.7	7487	-0.004
W1-5	8.47	5	10.33	0.28	0.55	13.4	312.50	0.002	32.08	0.082	231	15.5	8566	-0.009
W1-6	7.08	5.5	10.37	0.30	1.22	13.4	371.38	0.008	19.66	0.096	245	16.0	8944	-0.005
W1-7	5.25	5.8	10.39	0.32	1.38	13.9	378.71	0.840	43.27	0.095	247	18.2	9070	-0.004
W1-8	3.8	6	10.40	0.32	1.62	14.1	397.46	160	133.78	0.095	248	20.4	9126	0.003
W2-1	12.45	0	10.00	0.07	0.00	9.6	0.06	1.059	0.84	-0.002	0.8	17.0	934	0.006
W2-2	11.2	2.5	10.17	0.09	0.01	10.3	0.55	0.667	5.64	0.012	2.9	18.7	4356	0.003
W2-3	10.53	3.5	10.23	0.13	0.30	10.9	4.22	0.168	12.47	0.055	222	18.2	6811	-0.002
W2-4	9.43	4.3	10.29	0.18	0.40	11.3	161.00	0.041	24.02	0.091	232	16.4	7783	0.000
W2-5	8.54	4.8	10.32	0.30	0.62	12.6	305.34	0.010	38.88	0.096	239	17.3	8561	-0.001
W2-6	7.9	5.2	10.35	0.32	0.80	13.1	336.17	0.017	12.17	0.123	257	17.0	8933	0.000
W2-7	5.46	5.6	10.37	0.34	1.41	13.4	387.17	0.120	25.30	0.084	257	20.2	9491	-0.001
W2-8	3.74	6	10.40	0.36	1.58	13.9	412.83	214	141.36	0.108	255	23.8	9842	0.003
D2-1	12.4	0	10.00	0.11	0.00	21.6	0.09	0.808	0.45	0.005	0.8	210.3	912	0.008
D2-2	11.37	2.5	10.17	0.15	0.01	22.8	0.28	0.575	3.48	0.021	1.6	231.3	4489	0.000
D2-3	10.7	3.5	10.23	0.18	0.28	22.3	1.57	0.204	12.40	0.072	215	217.1	6586	-0.001
D2-4	9.36	4	10.27	0.32	0.54	23.3	222.01	0.048	19.65	0.082	236	198.2	8403	-0.005
D2-5	7.28	4.5	10.30	0.43	1.82	24.6	367.31	0.039	16.01	0.115	242	200.1	8842	-0.002
D2-6	5	5.5	10.37	0.45	2.72	25.7	399.00	4.630	43.44	0.086	249	221.9	9397	-0.007
D2-7	3.76	5.8	10.39	0.47	2.95	26.2	414.75	194	111.05	0.088	245	236.3	9433	0.002
H9-1	12.43	0	10.00	0.09	0.01	23.0	0.03	0.108	0.72	0.004	5.4	60.4	778.2	-0.002
H9-2	11.2	3.5	10.23	0.15	0.02	24.1	0.64	0.130	4.86	0.032	108	72.7	4756.2	-0.007
H9-3	10.47	5	10.33	0.16	0.13	25.8	3.49	0.034	20.29	0.093	226	73.6	6775.0	-0.012
H9-4	9.48	6	10.40	0.19	0.19	26.4	27.73	0.004	32.33	0.099	242	71.4	7970.7	-0.018
H9-5	8.25	6.7	10.45	0.21	0.33	26.8	53.35	0.016	34.10	0.274	246	71.2	8544.7	-0.013
H9-6	6.84	7	10.47	0.22	0.74	26.9	64.14	0.006	38.42	0.156	257	72.6	8942.4	-0.017
H9-7	5.25	7.25	10.48	0.23	1.28	27.4	72.66	0.900	40.51	0.082	258	74.2	9396.0	-0.020
H9-8	3.37	7.75	10.52	0.25	1.48	27.9	78.31	164	80.99	0.079	240	82.0	9530.4	-0.012

ANNEX 7.2 pH DEPENDENCE LEACHING TEST DATA

PH STAT DATA

15	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Mo	Cd
150	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
W1-1	-0.002	0.13	0.001	0.004	-0.007	-0.006	0.014	0.015	0.039	-0.002	10.607	0.044	0.001
W1-2	-0.002	1.36	0.002	0.009	0.003	0.007	0.010	0.005	0.058	0.012	15.978	0.346	0.000
W1-3	0.008	4.25	0.000	0.005	0.000	-0.002	0.006	0.012	0.011	0.039	18.488	0.491	-0.001
W1-4	0.021	5.02	0.001	0.001	-0.008	0.011	0.011	0.013	0.010	0.010	21.263	0.482	-0.001
W1-5	0.025	4.38	0.417	-0.005	0.007	0.400	0.000	0.005	-0.027	-0.005	22.948	0.371	-0.005
W1-6	0.004	4.95	2.854	0.002	0.084	1.598	0.009	3.331	0.008	0.045	24.036	0.381	0.001
W1-7	-0.004	3.96	3.816	0.008	0.110	2.752	0.044	7.686	0.025	0.035	24.769	0.128	-0.001
W1-8	0.001	3.34	4.966	0.881	0.153	4.935	0.313	11.776	0.010	0.015	25.315	0.049	0.004
W2-1	-0.001	0.37	0.001	0.000	0.002	0.010	0.011	0.030	0.028	0.017	10.516	0.168	-0.001
W2-2	-0.007	9.27	0.000	0.012	0.000	0.017	0.012	0.017	0.038	0.023	15.159	1.921	0.000
W2-3	0.005	19.65	0.000	0.007	-0.011	-0.004	0.013	0.004	0.075	0.050	18.488	2.514	-0.003
W2-4	0.026	21.17	0.004	0.002	-0.015	0.020	0.008	0.008	0.136	0.031	19.841	2.190	0.000
W2-5	0.005	20.43	0.461	0.006	0.014	0.309	0.005	0.005	0.101	-0.003	22.435	1.412	0.002
W2-6	-0.001	22.80	0.889	0.006	0.018	0.193	0.005	0.049	0.132	-0.003	23.571	2.799	0.000
W2-7	-0.010	21.97	3.292	0.010	0.113	1.000	0.029	35.815	0.003	0.013	25.261	1.139	0.012
W2-8	-0.009	22.33	4.486	0.896	0.127	1.634	0.386	47.296	-0.023	0.024	25.855	0.329	0.013
D2-1	0.000	0.02	0.001	0.000	0.019	0.006	0.021	0.024	0.040	0.023	10.932	-0.001	-0.002
D2-2	0.002	0.11	0.001	0.001	-0.007	-0.001	0.015	0.016	0.021	-0.001	16.877	0.006	0.000
D2-3	0.012	0.21	0.000	0.003	0.002	0.007	0.005	0.008	0.002	0.005	19.127	-0.001	0.000
D2-4	0.070	0.07	0.003	-0.003	0.047	0.046	0.000	0.010	0.056	0.022	22.046	0.027	0.005
D2-5	0.025	0.01	2.334	0.014	0.077	7.954	0.008	0.025	-0.004	0.041	23.527	0.012	0.004
D2-6	0.000	0.00	4.956	0.016	0.166	19.057	0.089	1.508	-0.020	-0.003	24.559	-0.009	-0.003
D2-7	0.002	0.13	5.919	15.314	0.193	21.289	0.481	2.107	-0.007	0.026	25.223	0.000	0.000
H9-1	0.000	0.02	0.000	0.002	-0.005	-0.002	-0.001	0.094	-0.011	0.005	6.293	0.002	0.000
H9-2	0.004	0.23	0.001	0.026	-0.014	-0.013	0.003	0.023	0.028	0.007	13.042	-0.007	0.002
H9-3	0.021	0.39	0.000	0.034	-0.011	-0.015	-0.004	0.053	-0.045	0.026	17.737	0.028	0.002
H9-4	0.054	0.37	0.000	0.010	0.020	-0.017	-0.006	0.012	0.002	0.036	19.887	0.006	-0.002
H9-5	0.040	0.18	0.126	0.023	-0.013	0.445	0.002	0.022	-0.035	0.023	20.613	-0.001	0.003
H9-6	0.004	0.16	2.305	0.022	0.051	3.545	-0.011	0.919	-0.016	0.024	21.479	-0.003	0.006
H9-7	0.000	0.16	4.414	0.019	0.107	10.592	0.030	7.518	-0.023	-0.016	22.251	-0.004	0.015
H9-8	0.003	0.17	7.167	11.563	0.184	15.922	0.393	8.796	-0.022	0.054	22.865	-0.002	0.018

PH STAT DATA

15	Sn	Sb	Ba	Pb	As hydr	Sb hydr	Se hydr	Tl	Be
150	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
W1-1	0.042	0.024	0.93	-0.004	-0.0001	0.0002	-0.0001	-0.001	0.0003
W1-2	0.018	-0.020	1.47	-0.011	0.001	-0.0002	-0.0001	-0.004	0.0004
W1-3	0.024	-0.006	1.03	-0.026	0.0039	0.002	0.0004	0.008	0.0001
W1-4	-0.010	-0.014	1.01	-0.008	0.0112	0.0121	0.0004	0.005	0.0001
W1-5	0.006	-0.037	1.28	-0.042	0.0226	0.0129	0.0002	-0.004	0
W1-6	0.053	0.030	1.96	-0.003	0.0012	0.0136	0	-0.003	0
W1-7	0.017	0.035	2.11	-0.044	0	0.008	-0.0003	-0.002	0.0004
W1-8	0.010	0.024	2.35	0.033	0.0009	0.0034	0.0001	-0.02	0.0104
W2-1	0.009	0.021	1.37	0.014	-0.0001	0.0009	0.0002	0.02	0.0001
W2-2	0.066	0.016	1.60	0.081	0.008	0.0013	0.0004	0.004	0
W2-3	-0.005	0.015	1.09	-0.060	0.0416	0.0316	0.001	0.012	-0.0001
W2-4	0.085	0.050	1.02	-0.006	0.0872	0.0601	0.001	0.021	0.0001
W2-5	0.057	0.051	1.27	-0.038	0.0553	0.0376	0.0006	0.011	0.0001
W2-6	0.004	0.088	1.39	0.035	0.0864	0.067	0.0009	0.007	0
W2-7	-0.019	0.002	1.79	0.172	0.0032	0.0402	0.0002	0.007	0
W2-8	0.025	0.005	1.91	0.045	0.0066	0.0166	0.0002	0.01	0.0127
D2-1	0.008	0.035	1.08	-0.012					
D2-2	-0.001	0.008	1.73	0.031					
D2-3	0.015	0.009	1.11	0.008					
D2-4	0.028	0.007	1.35	-0.045					
D2-5	0.000	-0.013	1.91	-0.026					
D2-6	-0.005	-0.013	2.26	0.001					
D2-7	0.002	0.019	2.67	0.244					
H9-1	-0.003	0.002	1.73	0.044					
H9-2	0.027	-0.011	1.66	-0.074					
H9-3	0.004	-0.021	1.52	-0.006					
H9-4	0.003	-0.012	1.95	0.002					
H9-5	0.000	-0.023	2.04	0.048					
H9-6	0.009	0.001	1.69	0.039					
H9-7	0.009	-0.020	1.61	-0.114					
H9-8	-0.020	0.028	1.87	0.811					

ANNEX 7.3 TANK LEACH TEST NEN 7345 (pH control pH=8)

H1				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.3	341.2	32.4	0.1	4.3	9.3	0.5	0.1	3.2	2.1	13.3	0.2	2.3	1.0
2.00	8.00		0.3	61.0	54.8	0.5	0.5	2.9	1.4	0.5	0.1	3.2	25.9	1.3	1.9	1.9
3.00	7.30		0.2	38.9	23.0	0.1	5.4	2.0	0.6	0.5	1.8	2.1	10.3	2.0	0.6	4.9
4.00	8.50		0.1	151.3	17.1	0.5	1.3	0.5	0.3	0.2	0.3	2.6	3.2	1.7	1.1	2.3
5.00	6.80		0.5	17.0	45.7	0.3	1.8	0.4	0.5	1.3	0.7	6.3	0.6	4.5	7.4	1.5
6.00	7.20		0.8	19.3	112.0	0.1	3.8	2.2	1.2	5.6	1.5	0.7	13.4	2.3	10.1	9.7
7.00	6.86		1.3	10.3	162.7	2.1	0.2	6.0	1.7	19.9	16.3	7.4	29.9	8.8	22.0	18.7
8.00	6.70		1.47	14.50	179.50	0.28	3.32	13.40	13.50	40.90	11.10	19.80	9.39	5.43	7.67	26.00
Fraction	Time (hr)	pH	Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00	8.00	0.25	15.20	1.44	0.00	0.19	0.41	0.02	0.00	0.14	0.09	0.59	0.01	0.10	0.04
2.00	24.00	8.00	1.00	17.90	3.88	0.03	0.21	0.54	0.08	0.03	0.15	0.24	1.74	0.07	0.19	0.13
3.00	54.00	7.30	2.25	19.60	4.90	0.03	0.45	0.63	0.11	0.05	0.23	0.33	2.20	0.16	0.21	0.35
4.00	96.00	8.50	4.00	26.30	5.66	0.05	0.51	0.65	0.12	0.06	0.24	0.44	2.34	0.23	0.26	0.45
5.00	218.00	6.80	9.08	27.10	7.69	0.07	0.59	0.67	0.15	0.12	0.27	0.72	2.37	0.43	0.59	0.52
6.00	384.00	7.20	16.00	27.90	12.70	0.07	0.76	0.77	0.20	0.36	0.34	0.76	2.96	0.53	1.04	0.95
7.00	864.00	6.86	36.00	28.40	19.90	0.16	0.77	1.04	0.28	1.25	1.06	1.08	4.29	0.92	2.02	1.78
8.00	1536.00	6.70	64.00	29.00	27.90	0.18	0.92	1.63	0.88	3.07	1.56	1.96	4.71	1.17	2.36	2.93

H5				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.38	506.20	31.70	0.50	1.80	33.90	0.10	0.50	1.90	4.30	10.20	5.10	1.00	0.40
2.00	8.00		0.35	155.30	61.20	0.40	4.20	16.40	1.90	0.30	2.50	5.70	27.70	10.30	1.90	0.40
3.00	7.30		0.16	44.30	29.70	0.50	5.10	5.70	0.40	0.30	1.20	2.20	20.00	1.50	1.10	0.80
4.00	8.00		0.16	105.70	19.90	0.20	0.60	1.00	1.90	0.50	1.90	5.20	5.60	0.70	3.40	0.50
5.00	6.90		0.50	22.60	39.70	0.10	3.10	0.30	1.00	3.30	0.40	3.40	2.60	3.40	1.00	0.20
6.00	7.80		0.55	25.50	62.90	1.50	13.70	6.10	11.90	2.40	35.60	19.00	25.90	28.10	4.80	3.00
7.00	7.09		0.70	13.10	97.90	0.40	1.10	13.40	0.40	8.40	0.30	4.40	7.80	5.30	15.30	3.00
8.00	6.43		1.50	6.41	214.70	0.90	3.97	28.10	0.45	106.20	7.77	34.90	20.90	7.95	1.25	5.60
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	22.50	1.41	0.02	0.08	1.51	0.00	0.02	0.08	0.19	0.45	0.23	0.04	0.02
2.00	24.00		1.00	29.40	4.13	0.04	0.27	2.24	0.09	0.04	0.20	0.44	1.68	0.68	0.13	0.04
3.00	54.00		2.25	31.40	5.45	0.06	0.49	2.49	0.11	0.05	0.25	0.54	2.57	0.75	0.18	0.07
4.00	96.00		4.00	36.10	6.33	0.07	0.52	2.53	0.19	0.07	0.33	0.77	2.82	0.78	0.33	0.09
5.00	218.00		9.08	37.10	8.10	0.08	0.66	2.55	0.24	0.22	0.35	0.92	2.94	0.93	0.37	0.10
6.00	384.00		16.00	38.20	10.90	0.14	1.27	2.82	0.76	0.32	1.93	1.77	4.09	2.18	0.59	0.24
7.00	864.00		36.00	38.80	15.20	0.16	1.32	3.41	0.78	0.70	1.95	1.96	4.44	2.42	1.27	0.37
8.00	1536.00		64.00	39.10	24.80	0.20	1.49	4.66	0.80	5.42	2.29	3.51	5.36	2.77	1.32	0.62

H1	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	2.9	5388	15648	13.3	0.6	31218	17.8	43799	38.1	32	8.4	6.1	2021	324	0.1
2.00	2.1	1545	6469	15.2	5.0	40271	0.9	18386	28.0	40	4.7	1.4	2626	515	0.4
3.00	2.1	1222	5640	13.9	7.4	15543	0.6	16278	20.4	53	5.1	0.9	3237	248	0.5
4.00	0.9	605	5831	10.0	13.1	12770	1.1	17300	20.1	32	2.2	6.5	1490	193	0.3
5.00	5.4	679	11379	14.1	38.0	69693	1.4	34225	33.7	68	15.4	6.0	1754	456	0.5
6.00	11.3	3336	15130	16.8	112.1	155918	1.7	41654	58.2	533	40.1	2.5	10379	1213	1.2
7.00	22.2	6357	27097	31.1	49.7	234295	3.4	71189	104.7	1017	54.9	18.0	16695	1742	1.4
8.00	44.00	15219	26678	1.66	81.50	340799	11.70	63223	122.70	2423	48.80	4.14	22192	2040	4.60
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.13	239	695	0.59	0.03	1387	0.79	1947	1.69	1	0.37	0.27	90	14	0.00
2.00	0.22	308	983	1.27	0.25	3177	0.83	2764	2.94	3	0.58	0.33	207	37	0.02
3.00	0.32	362	1234	1.88	0.58	3868	0.86	3487	3.84	6	0.81	0.37	350	48	0.04
4.00	0.36	389	1493	2.33	1.16	4436	0.91	4256	4.74	7	0.91	0.66	417	57	0.06
5.00	0.60	419	1999	2.96	2.85	7533	0.97	5777	6.24	10	1.59	0.93	495	77	0.08
6.00	1.10	568	2671	3.70	7.83	14463	1.04	7629	8.82	34	3.37	1.04	956	131	0.13
7.00	2.08	850	3875	5.08	10.00	24876	1.20	10792	13.50	79	5.81	1.84	1698	209	0.20
8.00	4.04	1527	5061	5.16	13.70	40023	1.71	13602	18.90	187	7.98	2.02	2684	299	0.40

H5	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	1.30	3417	16629	1.00	1.40	33596	3.00	54077	18.30	52	12.50	4.60	1837	146	0.50
2.00	1.40	1142	7295	2.50	0.20	58677	1.20	23490	15.10	33	3.90	2.90	2067	278	1.20
3.00	1.30	503	6912	10.20	5.40	14999	1.20	22511	13.00	74	2.30	4.30	2420	122	0.40
4.00	0.90	239	6803	13.00	15.50	16447	0.10	22901	9.40	59	2.70	2.70	1020	85	0.50
5.00	3.80	212	12778	10.20	47.20	81348	0.90	43578	17.60	206	2.00	3.40	1197	177	0.80
6.00	2.90	1334	16213	95.90	128.60	75223	3.10	54030	29.90	1343	18.40	29.30	5838	324	6.40
7.00	2.90	2638	29931	17.00	47.50	71731	2.40	91524	64.70	4149	17.40	1.30	12880	570	0.10
8.00	3.61	6114	27419	8.31	45.80	315499	3.58	72147	77.20	10310	26.20	11.20	21673	856	2.17
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.06	152	739	0.04	0.06	1493	0.13	2403	0.81	2	0.56	0.20	82	6	0.02
2.00	0.12	203	1063	0.16	0.07	4101	0.19	3447	1.48	4	0.73	0.33	174	19	0.08
3.00	0.18	225	1370	0.61	0.31	4768	0.24	4448	2.06	7	0.83	0.52	281	24	0.09
4.00	0.22	236	1673	1.19	1.00	5499	0.24	5466	2.48	10	0.95	0.64	326	28	0.12
5.00	0.39	245	2241	1.64	3.10	9114	0.28	7402	3.26	19	1.04	0.80	380	36	0.15
6.00	0.52	305	2961	5.90	8.81	12457	0.42	9804	4.59	79	1.86	2.10	639	50	0.44
7.00	0.64	422	4292	6.66	10.90	15645	0.53	13872	7.47	263	2.63	2.16	1212	76	0.44
8.00	0.80	693	5510	7.03	13.00	29668	0.69	17078	10.90	721	3.79	2.65	2175	114	0.54

N1				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.55	190.40	32.00	0.30	0.70	10.50	1.40	0.50	1.60	2.70	30.40	8.30	1.30	0.30
2.00	8.00		0.32	77.70	32.60	0.10	6.60	8.00	0.90	0.60	0.30	5.80	20.20	4.20	5.50	0.70
3.00	7.30		0.15	369.40	34.70	0.50	0.10	5.70	1.60	0.30	1.40	1.00	7.40	7.90	0.40	0.60
4.00	7.70		0.13	42.00	16.90	0.50	4.20	1.70	0.80	0.50	1.80	3.60	25.00	4.40	0.10	0.70
5.00	7.00		0.40	49.90	8.60	0.20	1.10	0.90	0.10	0.10	2.50	1.70	27.60	0.40	0.70	0.50
6.00	7.20		0.76	25.70	18.20	0.60	4.00	1.40	6.80	0.70	2.90	5.10	14.00	2.10	2.60	0.30
7.00	6.62		1.28	13.20	75.30	0.50	2.30	5.40	2.60	11.80	2.30	6.00	8.70	4.90	20.50	4.50
8.00	6.46		1.75	5.09	90.50	0.91	6.73	11.60	3.28	24.70	13.00	21.10	8.82	1.27	16.60	9.10
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	8.46	1.42	0.01	0.03	0.47	0.06	0.02	0.07	0.12	1.35	0.37	0.06	0.01
2.00	24.00		1.00	11.90	2.87	0.02	0.32	0.82	0.10	0.05	0.08	0.38	2.25	0.56	0.30	0.04
3.00	54.00		2.25	28.30	4.41	0.04	0.33	1.08	0.17	0.06	0.15	0.42	2.58	0.91	0.32	0.07
4.00	96.00		4.00	30.20	5.16	0.06	0.52	1.15	0.21	0.08	0.23	0.58	3.69	1.10	0.32	0.10
5.00	218.00		9.08	32.40	5.55	0.07	0.56	1.19	0.21	0.09	0.34	0.66	4.92	1.12	0.36	0.12
6.00	384.00		16.00	33.60	6.36	0.10	0.74	1.25	0.52	0.12	0.47	0.88	5.54	1.21	0.47	0.14
7.00	864.00		36.00	34.10	9.70	0.12	0.84	1.49	0.63	0.64	0.57	1.15	5.92	1.43	1.38	0.34
8.00	1536.00		64.00	34.40	13.70	0.16	1.14	2.01	0.78	1.74	1.15	2.09	6.32	1.49	2.12	0.74

N2				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.40	10.80	37.40	0.30	0.40	2.00	0.90	1.80	0.50	3.80	19.30	0.70	8.60	1.70
2.00	8.00		0.38	85.30	50.90	0.50	0.50	3.80	0.30	0.50	0.70	6.30	7.90	2.00	0.70	0.70
3.00	7.60		0.16	97.10	24.70	0.10	3.00	1.00	0.10	0.40	0.50	2.20	20.50	5.50	0.30	0.40
4.00	8.00		0.14	155.10	16.80	0.40	2.50	0.20	2.00	0.40	1.40	1.40	42.70	4.10	0.40	0.80
5.00	6.70		0.50	25.00	31.70	0.30	2.60	0.20	0.20	1.20	0.40	5.00	3.20	0.90	3.50	1.30
6.00	7.00		0.78	11.70	62.30	0.50	3.00	0.90	0.60	2.70	1.40	2.80	6.70	9.80	8.80	1.00
7.00	6.64		1.40	15.90	123.50	1.70	3.60	2.90	0.50	9.20	10.20	7.00	5.30	4.70	28.30	2.80
8.00	6.46		1.65	5.70	139.20	0.74	3.67	6.52	0.92	14.50	6.34	10.60	1.75	3.40	5.99	4.69
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	0.48	1.66	0.01	0.02	0.09	0.04	0.08	0.02	0.17	0.86	0.03	0.38	0.08
2.00	24.00		1.00	4.27	3.92	0.04	0.04	0.26	0.05	0.10	0.05	0.45	1.21	0.12	0.41	0.11
3.00	54.00		2.25	8.59	5.02	0.04	0.17	0.30	0.06	0.12	0.08	0.55	2.12	0.36	0.43	0.12
4.00	96.00		4.00	15.50	5.77	0.06	0.28	0.31	0.15	0.14	0.14	0.61	4.02	0.55	0.44	0.16
5.00	218.00		9.08	16.60	7.18	0.07	0.40	0.32	0.16	0.19	0.16	0.83	4.16	0.59	0.60	0.22
6.00	384.00		16.00	17.10	9.95	0.09	0.53	0.36	0.18	0.31	0.22	0.96	4.46	1.02	0.99	0.26
7.00	864.00		36.00	17.80	15.40	0.17	0.69	0.49	0.20	0.72	0.67	1.27	4.69	1.23	2.25	0.39
8.00	1536.00		64.00	18.10	21.60	0.20	0.86	0.78	0.25	1.37	0.95	1.74	4.77	1.38	2.52	0.59

N1	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	1.60	2610	9450	4.70	3.10	65963	9.70	28457	23.60	28	4.30	1.70	1170	332	0.20
2.00	3.90	1872	3665	10.70	3.10	62263	0.30	11035	16.70	43	2.90	0.20	2887	359	0.10
3.00	3.40	3183	14924	1.30	0.90	48285	14.20	49445	18.10	28	3.00	2.00	1578	310	0.50
4.00	3.20	715	3417	4.10	5.40	22984	1.30	11412	13.40	60	4.40	2.00	3073	192	0.20
5.00	1.00	239	2571	1.10	8.60	15558	1.20	8339	10.00	31	1.50	2.30	1376	100	0.50
6.00	8.00	314	7063	22.40	40.60	83764	1.10	23190	19.90	73	8.70	2.10	1245	222	0.70
7.00	5.10	3315	16179	12.60	36.30	259244	6.70	45138	63.60	2386	35.10	8.50	20494	952	1.60
8.00	3.37	8898	16149	14.30	41.80	400817	4.73	40610	77.00	6111	36.60	11.20	32433	1191	3.09
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.07	116	420	0.21	0.14	2932	0.43	1265	1.05	1	0.19	0.08	52	15	0.01
2.00	0.24	199	583	0.68	0.28	5699	0.44	1755	1.79	3	0.32	0.08	180	31	0.01
3.00	0.40	341	1246	0.74	0.32	7845	1.08	3953	2.60	4	0.45	0.17	250	45	0.04
4.00	0.54	373	1398	0.92	0.56	8866	1.13	4460	3.19	7	0.65	0.26	387	53	0.04
5.00	0.58	383	1512	0.97	0.94	9558	1.19	4831	3.64	8	0.72	0.36	448	57	0.07
6.00	0.94	397	1826	1.97	2.74	13281	1.24	5861	4.52	12	1.10	0.46	504	67	0.10
7.00	1.16	545	2545	2.53	4.36	24803	1.53	7867	7.35	118	2.66	0.84	1414	110	0.17
8.00	1.31	940	3263	3.16	6.21	42617	1.74	9672	10.80	389	4.29	1.33	2856	163	0.31

N2	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	4.60	798	7878	6.10	98.70	134520	1.10	23586	28.80	571	12.40	1.20	6766	486	0.20
2.00	4.00	2007	6733	4.90	7.50	66415	2.00	22345	13.40	45	4.30	1.80	2807	442	0.50
3.00	1.70	893	6005	3.80	4.70	16797	0.70	20380	11.80	93	8.50	1.30	3125	217	0.20
4.00	0.70	331	6018	5.00	14.00	13404	0.80	20857	9.40	65	3.30	4.50	1698	143	0.10
5.00	3.20	358	10404	4.90	32.70	82780	3.00	37174	13.50	177	7.20	2.00	1399	266	0.30
6.00	4.60	807	14594	18.80	112.80	140089	2.50	47686	26.30	1337	20.60	2.80	6056	597	0.70
7.00	5.80	3657	27565	19.70	39.80	254467	6.40	81414	61.50	5360	38.00	13.60	16857	1238	1.90
8.00	1.75	8220	25572	2.02	52.50	373342	5.24	67216	75.20	11841	24.00	0.64	24558	1422	3.77
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.20	35	350	0.27	4.39	5979	0.05	1048	1.28	25	0.55	0.05	301	22	0.01
2.00	0.38	125	649	0.49	4.72	8930	0.14	2041	1.88	27	0.74	0.13	426	41	0.03
3.00	0.46	164	916	0.66	4.93	9677	0.17	2947	2.40	32	1.12	0.19	564	51	0.04
4.00	0.49	179	1184	0.88	5.55	10273	0.20	3874	2.82	34	1.27	0.39	640	57	0.04
5.00	0.63	195	1646	1.10	7.00	13952	0.34	5526	3.42	42	1.59	0.48	702	69	0.06
6.00	0.84	231	2295	1.93	12.00	20178	0.45	7646	4.59	102	2.50	0.60	971	96	0.09
7.00	1.09	393	3520	2.81	13.80	31488	0.73	11264	7.32	340	4.19	1.21	1720	151	0.17
8.00	1.17	759	4656	2.90	16.10	48081	0.97	14251	10.70	866	5.26	1.24	2812	214	0.34

D1				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.25	495.70	29.10	0.40	1.90	7.60	0.20	0.40	0.30	8.00	9.60	5.80	2.80	0.20
2.00	8.00		0.29	92.30	44.50	0.30	1.70	4.00	0.80	0.20	1.60	2.80	34.20	2.00	0.20	0.50
3.00	7.50		0.18	84.90	28.10	0.40	3.00	0.90	0.40	0.30	3.70	4.30	3.30	3.80	1.40	0.60
4.00	8.90		0.15	217.60	17.90	0.50	1.70	0.60	0.10	0.30	1.00	0.80	21.50	2.80	1.40	0.70
5.00	6.80		0.46	22.00	36.20	0.10	0.40	0.20	0.30	1.30	1.00	1.30	15.50	7.80	2.80	0.40
6.00	6.80		0.84	10.60	80.70	0.10	0.20	0.50	0.70	3.40	4.90	0.80	25.40	2.30	12.60	1.10
7.00	6.70		1.52	17.30	169.80	0.20	1.50	11.70	2.30	5.70	2.70	12.50	0.20	4.80	23.20	5.30
8.00	6.50		1.61	4.53	176.10	0.36	2.40	6.39	0.18	9.15	9.32	3.82	40.10	11.70	2.00	5.42
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	22.00	1.29	0.02	0.08	0.34	0.01	0.02	0.01	0.36	0.43	0.26	0.12	0.01
2.00	24.00		1.00	26.10	3.27	0.03	0.16	0.52	0.04	0.03	0.08	0.48	1.95	0.35	0.13	0.03
3.00	54.00		2.25	29.90	4.52	0.04	0.29	0.56	0.06	0.04	0.25	0.67	2.09	0.52	0.20	0.06
4.00	96.00		4.00	39.60	5.32	0.07	0.37	0.58	0.07	0.05	0.29	0.71	3.05	0.64	0.26	0.09
5.00	218.00		9.08	40.60	6.92	0.07	0.39	0.59	0.08	0.11	0.34	0.76	3.74	0.99	0.38	0.11
6.00	384.00		16.00	41.00	10.50	0.08	0.40	0.61	0.11	0.26	0.56	0.80	4.87	1.09	0.94	0.16
7.00	864.00		36.00	41.80	18.10	0.08	0.46	1.13	0.21	0.52	0.68	1.36	4.88	1.30	1.97	0.39
8.00	1536.00		64.00	42.00	25.90	0.10	0.57	1.42	0.22	0.92	1.09	1.53	6.66	1.82	2.06	0.63

D2				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.66	294.40	34.20	0.50	4.30	0.60	0.60	0.10	0.50	11.20	0.50	0.60	0.10	0.50
2.00	8.00		0.36	99.10	48.20	0.10	4.40	0.40	0.90	0.60	2.20	14.10	13.30	5.30	0.50	0.10
3.00	7.40		0.21	82.60	21.30	0.10	1.90	0.50	1.20	0.20	1.50	3.90	9.50	5.30	0.20	0.50
4.00	8.88		0.18	198.00	14.60	0.10	0.80	0.80	0.50	0.20	4.60	5.20	0.10	1.00	0.70	0.70
5.00	6.80		0.49	37.50	24.70	0.70	1.90	0.20	0.40	1.10	2.10	5.20	1.60	4.40	0.30	0.80
6.00	6.80		1.13	10.70	77.30	0.40	0.40	0.60	1.50	13.10	3.80	0.30	11.70	6.10	13.70	2.30
7.00	6.76		1.40	21.00	99.60	3.20	1.70	1.50	0.50	16.30	19.00	9.50	10.30	0.10	33.70	2.80
8.00	6.40		1.92	8.51	126.80	0.86	2.24	0.17	1.63	48.60	14.60	15.20	13.90	6.45	1.78	4.81
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	13.10	1.52	0.02	0.19	0.03	0.03	0.00	0.02	0.50	0.02	0.03	0.00	0.02
2.00	24.00		1.00	17.50	3.66	0.03	0.39	0.04	0.07	0.03	0.12	1.12	0.61	0.26	0.03	0.03
3.00	54.00		2.25	21.20	4.61	0.03	0.47	0.07	0.12	0.04	0.19	1.30	1.04	0.50	0.04	0.05
4.00	96.00		4.00	30.00	5.26	0.04	0.51	0.10	0.14	0.05	0.39	1.53	1.04	0.54	0.07	0.08
5.00	218.00		9.08	31.60	6.36	0.07	0.59	0.11	0.16	0.10	0.48	1.76	1.11	0.74	0.08	0.12
6.00	384.00		16.00	32.10	9.79	0.08	0.61	0.14	0.23	0.68	0.65	1.77	1.63	1.01	0.69	0.22
7.00	864.00		36.00	33.00	14.20	0.23	0.68	0.20	0.25	1.40	1.50	2.20	2.09	1.01	2.19	0.34
8.00	1536.00		64.00	33.40	19.90	0.26	0.78	0.21	0.32	3.57	2.15	2.87	2.71	1.30	2.27	0.56

D1	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	2.20	4572	9286	3.00	0.50	47567	2.80	55076	19.70	50	3.40	1.00	1791	138	0.10
2.00	1.40	1704	4133	5.10	1.80	56319	0.40	23508	17.20	45	3.70	5.40	2751	214	0.40
3.00	1.10	949	4479	3.90	5.90	18989	1.70	25739	16.60	77	4.30	1.20	4175	123	0.60
4.00	0.10	446	4511	5.20	11.60	11647	0.60	26483	15.10	73	1.00	0.70	2839	78	0.30
5.00	2.60	296	6775	4.30	34.60	72068	0.90	41124	17.70	174	7.40	5.40	1828	134	0.30
6.00	5.40	1657	9100	13.50	119.70	157092	2.50	50785	33.50	1710	20.90	9.50	8585	298	0.10
7.00	8.10	9378	18141	23.20	77.00	296112	3.90	87449	84.70	9301	42.40	4.70	24330	712	2.10
8.00	4.80	7287	14542	6.48	40.70	343590	3.29	67115	70.20	6378	25.90	1.95	24047	636	2.04
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.10	203	413	0.13	0.02	2114	0.12	2448	0.88	2	0.15	0.04	80	6	0.00
2.00	0.16	279	596	0.36	0.10	4617	0.14	3493	1.64	4	0.32	0.28	202	16	0.02
3.00	0.21	321	795	0.53	0.36	5461	0.22	4637	2.38	8	0.51	0.34	387	21	0.05
4.00	0.21	341	996	0.76	0.88	5979	0.24	5814	3.05	11	0.55	0.37	514	25	0.06
5.00	0.33	354	1297	0.96	2.42	9182	0.28	7641	3.84	19	0.88	0.61	595	31	0.08
6.00	0.57	428	1701	1.56	7.74	16164	0.40	9898	5.32	95	1.81	1.03	976	44	0.08
7.00	0.93	845	2508	2.59	11.20	29324	0.57	13785	9.09	508	3.69	1.24	2058	75	0.17
8.00	1.14	1169	3154	2.87	13.00	44595	0.72	16768	12.20	791	4.85	1.33	3126	104	0.26

D2	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	1.70	2463	7062	1.70	0.40	43457	5.10	91495	17.60	24	4.50	5.60	1049	494	0.40
2.00	1.20	1372	3676	13.40	2.50	50749	2.60	49652	12.40	30	3.60	1.10	1551	689	0.20
3.00	3.90	654	3032	11.70	8.00	17274	0.40	41957	8.30	63	3.50	8.00	1640	279	0.10
4.00	1.00	270	2904	1.60	14.50	11876	1.50	41252	7.50	43	0.40	8.30	1109	184	0.30
5.00	3.40	450	5541	4.30	40.50	60260	1.60	79479	14.70	179	5.00	5.60	1501	355	0.60
6.00	7.00	1593	7868	27.70	128.50	186286	4.60	98483	30.80	5304	29.90	7.70	10031	1367	2.00
7.00	7.50	3042	12615	21.40	53.10	222614	5.30	149123	51.80	8425	41.60	20.20	16345	1782	1.80
8.00	9.97	9009	11853	20.20	104.40	372513	6.37	120886	75.50	24848	38.30	10.50	24697	2352	5.16
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.08	110	314	0.08	0.02	1931	0.23	4066	0.78	1	0.20	0.25	47	22	0.02
2.00	0.13	170	477	0.67	0.13	4187	0.34	6273	1.33	2	0.36	0.30	116	53	0.03
3.00	0.30	200	612	1.19	0.48	4955	0.36	8138	1.70	5	0.52	0.65	189	65	0.03
4.00	0.35	212	741	1.26	1.13	5483	0.43	9971	2.04	7	0.53	1.02	238	73	0.04
5.00	0.50	232	987	1.45	2.93	8161	0.50	13504	2.69	15	0.76	1.27	304	89	0.07
6.00	0.81	302	1337	2.68	8.64	16440	0.70	17881	4.06	251	2.08	1.61	750	150	0.16
7.00	1.14	437	1898	3.64	11.00	26334	0.94	24508	6.36	625	3.93	2.51	1477	229	0.24
8.00	1.59	838	2424	4.53	15.60	42890	1.22	29881	9.71	1730	5.64	2.98	2574	333	0.47

W1				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.39	418.50	35.40	0.10	0.30	13.90	1.00	0.50	3.40	1.90	4.90	8.90	1.30	0.50
2.00	8.00		0.27	56.90	34.60	0.50	2.80	13.40	0.40	0.50	4.00	2.00	26.30	0.50	0.10	0.80
3.00	7.40		0.13	40.80	12.80	0.70	3.20	6.00	1.60	0.60	1.30	2.60	20.20	0.20	4.40	1.00
4.00	7.40		0.18	32.80	11.30	0.30	3.00	1.00	1.00	0.50	0.50	7.10	3.30	0.60	3.00	0.60
5.00	7.10		0.47	22.40	37.70	0.20	0.80	0.10	1.00	1.10	3.00	2.50	5.40	7.00	4.60	0.30
6.00	7.00		1.19	9.20	87.30	0.50	0.60	16.50	1.20	13.20	12.30	0.20	5.60	3.00	20.10	3.10
7.00	6.74		1.73	15.40	128.60	0.80	1.50	41.60	4.10	34.40	25.00	12.10	1.30	1.20	37.70	5.30
8.00	6.40		1.69	8.69	112.40	1.18	4.12	18.00	3.20	36.90	15.70	14.90	1.94	9.79	6.94	5.10
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	18.60	1.57	0.00	0.01	0.62	0.04	0.02	0.15	0.08	0.22	0.40	0.06	0.02
2.00	24.00		1.00	21.10	3.11	0.03	0.14	1.21	0.06	0.04	0.33	0.17	1.39	0.42	0.06	0.06
3.00	54.00		2.25	22.90	3.68	0.06	0.28	1.48	0.13	0.07	0.39	0.29	2.28	0.43	0.26	0.10
4.00	96.00		4.00	24.40	4.18	0.07	0.41	1.52	0.18	0.09	0.41	0.60	2.43	0.45	0.39	0.13
5.00	218.00		9.08	25.40	5.86	0.08	0.45	1.53	0.22	0.14	0.54	0.72	2.67	0.76	0.60	0.14
6.00	384.00		16.00	25.80	9.74	0.10	0.48	2.26	0.28	0.73	1.09	0.72	2.92	0.90	1.49	0.28
7.00	864.00		36.00	26.50	15.50	0.14	0.54	4.11	0.46	2.26	2.20	1.26	2.98	0.95	3.16	0.52
8.00	1536.00		64.00	26.90	20.50	0.19	0.73	4.91	0.60	3.90	2.90	1.93	3.06	1.39	3.47	0.74

W2				Al	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sb	Sn	V
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	8.00		0.35	458.90	40.50	0.30	0.20	36.60	0.30	0.10	18.50	4.80	24.10	1.30	0.90	0.50
2.00	8.00		0.30	60.30	60.80	0.50	4.70	40.50	0.20	0.60	13.40	2.30	1.20	2.80	3.10	0.30
3.00	7.40		0.12	42.60	30.90	0.80	2.00	22.40	0.10	0.60	5.80	0.50	1.70	3.30	2.10	0.80
4.00	7.50		0.15	52.20	19.70	0.10	2.40	4.40	0.60	0.40	1.80	3.60	8.90	0.20	1.30	0.30
5.00	6.90		0.37	23.90	37.10	0.30	3.70	1.30	0.20	1.10	1.20	0.40	19.40	4.80	0.90	0.50
6.00	7.20		0.77	15.10	96.90	0.30	0.30	28.20	0.30	4.10	13.00	4.00	15.60	4.80	13.40	1.50
7.00	6.65		1.63	9.00	184.00	0.50	1.20	181.40	3.40	17.30	61.10	17.10	11.00	22.10	26.20	7.30
8.00	6.60		1.58	10.80	153.30	2.03	4.55	114.80	2.51	17.80	50.40	18.30	17.40	25.30	9.80	5.90
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	6.00		0.25	20.40	1.80	0.01	0.01	1.63	0.01	0.00	0.82	0.21	1.07	0.06	0.04	0.02
2.00	24.00		1.00	23.10	4.50	0.04	0.22	3.43	0.02	0.03	1.42	0.32	1.12	0.18	0.18	0.04
3.00	54.00		2.25	25.00	5.88	0.07	0.31	4.42	0.03	0.06	1.68	0.34	1.20	0.33	0.27	0.07
4.00	96.00		4.00	27.30	6.75	0.08	0.41	4.62	0.05	0.08	1.76	0.50	1.60	0.34	0.33	0.08
5.00	218.00		9.08	28.40	8.40	0.09	0.58	4.68	0.06	0.12	1.81	0.52	2.46	0.55	0.37	0.11
6.00	384.00		16.00	29.00	12.70	0.10	0.59	5.93	0.08	0.31	2.39	0.69	3.15	0.76	0.96	0.17
7.00	864.00		36.00	29.40	20.90	0.12	0.64	14.00	0.23	1.08	5.10	1.45	3.64	1.75	2.13	0.50
8.00	1536.00		64.00	29.90	27.70	0.21	0.85	19.10	0.34	1.87	7.34	2.27	4.41	2.87	2.56	0.76

W1	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	3.10	1802	4876	0.90	9.00	58383	0.10	7959	5.50	28	4.60	0.10	1250	564	0.30
2.00	7.40	1635	1315	9.40	5.00	58032	1.40	2841	6.90	43	7.90	1.50	2652	647	0.60
3.00	3.60	677	1287	2.60	7.90	25417	1.00	2514	4.80	103	21.50	1.20	2860	314	0.30
4.00	6.70	279	1543	3.20	19.10	33880	0.50	3577	3.30	97	4.20	0.60	767	248	0.60
5.00	10.60	358	4159	4.60	38.20	82243	1.00	8479	14.00	432	5.80	2.60	1093	824	0.50
6.00	52.20	5232	5321	17.60	131.90	255920	0.50	8271	31.00	9745	35.70	7.90	15040	2032	2.10
7.00	120.40	10956	9670	17.10	120.80	428646	12.40	14309	65.40	23987	59.90	15.40	24008	3043	8.20
8.00	135.50	5760	8256	0.64	57.00	407174	5.72	11440	55.40	15168	26.40	5.97	22855	2568	5.15
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.14	80	217	0.04	0.40	2595	0.00	354	0.24	1	0.20	0.00	56	25	0.01
2.00	0.47	153	275	0.46	0.62	5174	0.07	480	0.55	3	0.56	0.07	173	54	0.04
3.00	0.63	183	332	0.57	0.97	6304	0.11	592	0.76	8	1.51	0.12	301	68	0.05
4.00	0.92	195	401	0.72	1.82	7809	0.13	751	0.91	12	1.70	0.15	335	79	0.08
5.00	1.40	211	586	0.92	3.52	11465	0.18	1128	1.53	31	1.96	0.27	383	115	0.10
6.00	3.72	444	822	1.70	9.38	22839	0.20	1495	2.91	464	3.54	0.62	1052	206	0.20
7.00	9.07	931	1252	2.46	14.80	41890	0.75	2131	5.82	1530	6.20	1.30	2119	341	0.56
8.00	15.10	1187	1619	2.49	17.30	59986	1.01	2640	8.28	2205	7.38	1.57	3134	455	0.79

W2	Zn	SO4	Na	As	B	Ca	Fe	K	Li	Mg	P	Se	Si	Sr	Ti
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1.00	2.00	1458	4772	9.20	0.70	47227	1.30	9692	12.30	26	4.20	0.20	1237	526	1.20
2.00	2.30	1377	1198	8.80	4.20	62403	0.90	2711	8.00	35	2.80	2.20	2330	780	0.60
3.00	2.00	728	1584	7.00	6.90	21053	0.20	3610	8.20	84	6.00	3.00	2978	458	0.40
4.00	4.50	252	1603	7.00	14.80	28480	0.90	3543	6.40	110	4.30	4.10	1040	285	0.50
5.00	22.10	193	3679	13.70	38.40	75945	0.60	8269	13.00	197	5.80	3.00	790	542	0.10
6.00	109.20	1940	4899	13.80	107.70	151056	0.50	9657	27.70	3441	23.70	5.00	7598	1618	0.30
7.00	519.00	7518	8637	6.30	91.30	369244	3.90	15305	65.90	17394	56.00	13.70	21999	3145	4.70
8.00	499.10	6522	7310	3.00	63.30	360657	11.40	11864	60.90	14713	32.90	6.96	21221	2641	3.97
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1.00	0.09	65	212	0.41	0.03	2099	0.06	431	0.55	1	0.19	0.01	55	23	0.05
2.00	0.19	126	265	0.80	0.22	4872	0.10	551	0.90	3	0.31	0.11	159	58	0.08
3.00	0.28	158	336	1.11	0.52	5808	0.11	712	1.27	6	0.58	0.24	291	78	0.10
4.00	0.48	170	407	1.42	1.18	7074	0.15	869	1.55	11	0.77	0.42	337	91	0.12
5.00	1.46	178	570	2.03	2.89	10449	0.17	1237	2.13	20	1.03	0.56	372	115	0.12
6.00	6.32	264	788	2.64	7.68	17163	0.20	1666	3.36	173	2.08	0.78	710	187	0.14
7.00	29.40	599	1172	2.92	11.70	33574	0.37	2346	6.29	946	4.57	1.39	1688	327	0.35
8.00	51.60	888	1497	3.06	14.50	49603	0.87	2873	9.00	1600	6.03	1.70	2631	444	0.52

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORN1			Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	**µg/l**	µg/l	µg/l	**µg/l**	µg/l	µg/l
1	12.12	1.52	212.5		51	0.13	1.37	6.17	2.24	0.57	0.29	2.32
2	11.94	1.49	278.8		64.7	0.1	1.35	8.12	1.4	0.48	0.27	2.62
3	11.87	1.42	343.6	0.01	57.8	0.03	1.09	7.75	1.41	0.49	0.26	2.33
4	11.63	1.32	402.5		53.5	0.05	1.08	7.16	1.32	0.49	0.23	2.07
5	11.86	1.72	548		75.7	0.03	1.38	7.63	1.2	0.51	0.2	2.19
6	11.88	1.57	664.6		71.2	0.02	1.24	5.69	1.25	0.43	0.16	1.77
7	11.80	1.32	896		64.6	0.02	1.4	4.65	1.44	0.43	0.14	1.12
8	11.69	0.94	1004	0.04	36		1.1	3.9	1.6		0.1	1.05
Fraction	Time (hr)	Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6	0.25	9.21		2.21	0.006	0.059	0.27	0.097	0.025	0.013	0.1
2	24	1	21.3		5.01	0.01	0.12	0.62	0.16	0.046	0.024	0.21
3	54	2.25	36.2		7.52	0.011	0.17	0.96	0.22	0.067	0.036	0.32
4	96	4	53.6		9.83	0.013	0.21	1.27	0.28	0.088	0.046	0.4
5	218	9.08333	77.4		13.1	0.015	0.27	1.6	0.33	0.11	0.054	0.5
6	384	16	106.2		16.2	0.016	0.33	1.84	0.38	0.13	0.061	0.58
7	864	36	145		19	0.016	0.39	2.04	0.44	0.15	0.067	0.62
8	1536	64	188.5		20.6		0.43	2.21	0.51		0.072	0.67

NORN2			Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	11.86	1.5	238.7		63.8	0.073	1.43	4.41	1.52	0.19	0.28	3.31
2	11.88	1.43	331.5	0.037	76	0.015	1.19	5.09	0.67	0.14	0.2	3.04
3	11.84	1.53	490.2		81.7	0.031	1.14	5.07	0.36	0.095	0.22	3.18
4	11.86	1.53	598.3		84.8	0.036	1.11	4.81	0.63	0.15	0.18	3.34
5	11.87	2.06	783.2	0.012	134.4	0.023	1.76	4.8	0.91	0.17	0.19	4
6	11.68	1.96	930.1		112.9	0.04	1.6	3.96	1.07	0.21	0.18	3.6
7	11.98	2.12	1066	0.02	119		2	3.6	2.1		0.13	1.05
8	11.87	1.67	1378	0.03	77		2.1	2.5	2.4		0.09	0.95
Fraction	Time (hr)	Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6	0.25	10.3		2.77	0.003	0.062	0.19	0.066	0.008	0.012	0.14
2	24	1	24.7		6.06	0.004	0.11	0.41	0.095	0.014	0.021	0.28
3	54	2.25	45.9		9.6	0.005	0.16	0.63	0.11	0.019	0.03	0.41
4	96	4	71.9		13.3	0.007	0.21	0.84	0.14	0.025	0.038	0.56
5	218	9.08333	105.8		19.1	0.008	0.29	1.05	0.18	0.033	0.046	0.73
6	384	16	146.1		24	0.009	0.36	1.22	0.22	0.042	0.054	0.89
7	864	36	192.3		29.2		0.44	1.37	0.31		0.06	0.93
8	1536	64	252		32.5		0.53	1.48	0.42		0.064	0.97

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORN1	Pb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
1	0.22	4.05	0.03	0.02	8.53	1000		12.12	1.517	22.2	8180	23300
2	0.08	3.33	0.02	0.03	5.66	1160		11.94	1.494	21.5	4560	13600
3	0.12	1.04	0.02	0.08	8.78	1000		11.87	1.419	20.3	4170	12300
4	0.22	0.92	0.02	0.12	4.75	930		11.63	1.318	21.1	4100	12300
5	0.1	0.61	0.02	0.04	3.52	880		11.86	1.715	22.5	8600	25500
6	0.19	0.97	0.02	0.08	4.55	840		11.88	1.565	21.8	8700	26500
7	0.05	0.81	0.04	0.11	1.04	780		11.8	1.321	20.7	13400	39000
8	0.1	0.4	0.03	0.6	1.3	1260		11.69	0.939	21.8	17300	47800
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	pH	mS/cm	C	mg/m2	mg/m2
1	0.01	0.18	0.001	0.001	0.37	43.3		11.86	1.5	20.6	354.5	1010
2	0.013	0.32	0.002	0.002	0.61	93.6		11.88	1.432	21	552.1	1599
3	0.018	0.36	0.003	0.006	1	136.9		11.84	1.53	21.9	732.8	2132
4	0.028	0.4	0.004	0.011	1.2	177.2		11.86	1.53	20.8	910.4	2665
5	0.032	0.43	0.005	0.013	1.35	215.4		11.87	2.064	21	1283	3770
6	0.04	0.47	0.006	0.016	1.55	251.8		11.68	1.956	22.3	1660	4918
7	0.042	0.51	0.007	0.021	1.6	285.6		11.98	2.122	21.7	2241	6608
8	0.047	0.53	0.009	0.047	1.65	340.2		11.87	1.67	23	2990	8680
NORN2	Pb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
1	0.16	0.66	0.039	0.031	3.19	1530		12.08	1.344	22.2	13900	43000
2	0.072	0.44	0.014		1.69	550		11.91	1.448	22.4	7450	25000
3	0.008	0.66			2.24	1390		11.84	1.305	20.6	7450	25000
4	0.065	0.27			1.62	1320		11.67	1.279	21	7750	25800
5	0.069	0.61			1.58	1030		11.88	1.727	22.4	15100	49500
6	0.16	0.45			5.19	970		11.88	1.535	21.8	15500	47500
7	0.13	0.24		0.06	1	870		11.83	1.42	20.8	23500	70000
8	0.2	0.4		0.15	2.5	1000		11.66	0.903	21.8	29200	81000
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	pH	mS/cm	C	mg/m2	mg/m2
1	0.007	0.028	0.002	0.001	0.14	66.3		11.94	1.824	20.7	602.3	1863
2	0.01	0.047	0.002		0.21	90.1		11.93	1.682	21.1	925.2	2947
3	0.01	0.076			0.31	150.4		11.89	1.753	21.9	1248	4030
4	0.013	0.088			0.38	207.6		11.9	1.668	20.8	1584	5148
5	0.016	0.11			0.45	252.2		11.97	2.227	21.2	2238	7293
6	0.023	0.13			0.67	294.2		11.69	1.905	22.2	2910	9351
7	0.029	0.14			0.72	331.9		11.91	1.673	21.6	3928	12385
8	0.037	0.16			0.82	375.3		11.81	1.461	23.1	5194	15895

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORD1			Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	12.08	1.34	275.2		63.2	0.09	0.57	4.49	1.88	0.61	0.26	1.01
2	11.91	1.45	465.6		110.4	0.09	0.64	4.51	1.46	0.63	0.22	1.89
3	11.84	1.31	507.9		101.2	0.03	0.6	3.76	0.94	0.52	0.16	1.32
4	11.67	1.28	551.6		102.6	0.02	0.55	3.43	0.97	0.46	0.13	1.38
5	11.88	1.73	743.9		154.2	0.01	0.7	3.68	1.19	0.49	0.15	1.52
6	11.88	1.54	853.6		129.6	0.04	0.57	2.94	1.34	0.52	0.19	1.14
7	11.83	1.42	1072		116.3	0.03	0.54	2.1	1.54	0.51	0.14	0.58
8	11.66	0.9	1505	0.05	47.9	0.01	0.25	2.8	1.35		0.07	0.15
Fraction	Time (hr)	Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6	0.25	11.9		2.74	0.004	0.025	0.19	0.081	0.026	0.011	0.044
2	24	1	32.1		7.52	0.008	0.052	0.39	0.14	0.054	0.021	0.13
3	54	2.25	54.1		11.9	0.009	0.078	0.55	0.19	0.076	0.028	0.18
4	96	4	78		16.4	0.01	0.1	0.7	0.23	0.096	0.033	0.24
5	218	9.08333	110.2		23	0.01	0.13	0.86	0.28	0.12	0.04	0.31
6	384	16	147.2		28.7	0.012	0.16	0.99	0.34	0.14	0.048	0.36
7	864	36	193.7		33.7	0.013	0.18	1.08	0.4	0.16	0.054	0.38
8	1536	64	258.9		35.8	0.014	0.19	1.2	0.46		0.057	0.39
NORD2			Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	11.94	1.82	198.1	0.04	57.9	0.04	0.57	0.89	1.28	0.24	0.25	2.99
2	11.93	1.68	380.1		74.5	0.04	0.57	0.97	2.2	0.34	0.25	3.55
3	11.89	1.75	585.7		79.1		0.62	0.94	0.46	0.21	0.17	3.72
4	11.9	1.67	670.2	0.03	77.3	0.04	0.52	0.87	0.51	0.77	0.16	3.42
5	11.97	2.23	830.7	0.02	111.7	0.02	0.71	0.75	1.05	0.28	0.13	3.6
6	11.69	1.91	902.8		82.9	0.02	0.55	0.5	1.11	0.29	0.12	2.84
7	11.91	1.67	1072	0.02	58		0.32	0.7	1.9		0.09	0.92
8	11.81	1.46	1481	0.03	49		0.24	0.46	2.2		0.07	0.3
Fraction	Time (hr)	Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6	0.25	8.58	0.002	2.51	0.002	0.025	0.039	0.055	0.01	0.011	0.13
2	24	1	25.1		5.74	0.003	0.049	0.081	0.15	0.025	0.022	0.28
3	54	2.25	50.4		9.16		0.076	0.12	0.17	0.034	0.029	0.44
4	96	4	79.5		12.5		0.099	0.16	0.19	0.068	0.036	0.59
5	218	9.08333	115.5		17.4		0.13	0.19	0.24	0.08	0.042	0.75
6	384	16	154.6		20.9		0.15	0.21	0.29	0.092	0.047	0.87
7	864	36	201		23.5		0.17	0.24	0.37		0.051	0.91
8	1536	64	265.2		25.6		0.18	0.26	0.46		0.054	0.92

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORD1		Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
	1	0.52	0.03	4.6	0.04		4.59	1.6		12.06	1.254	22.2	9350	52000
	2	0.43	0.01	3.72	0.04	0.01	7.23	1.4		11.87	1.254	21.3	5000	29000
	3	0.41	0.02	1.15	0.04	0.02	4.33	1.08		11.78	1.189	20.3	4400	24300
	4	0.31	0.03	0.81	0.06	0.04	3.47	0.98		11.52	1.185	21	4430	25500
	5	0.43	0.03	0.51	0.05		3.64	0.89		11.85	1.592	22.4	8850	49500
	6	0.31	0.03	0.74	0.03		2.69	0.89		11.82	1.424	21.6	8700	46500
	7	0.32	0.04	0.61	0.07	0.02	1.08	0.82		11.76	1.303	20.7	12300	65300
	8	0.16	0.08	0.27	0.05	2.39	0.17	2.6		11.77	1.217	21.8	15400	76000
Fraction		mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	pH	mS/cm	C	mg/m2	mg/m2
	1	0.023	0.001	0.2	0.002		0.2	0.069		12.02	1.186	22.2	405.2	2253
	2	0.041	0.002	0.36	0.003		0.51	0.13		11.91	1.381	21.8	621.8	3510
	3	0.059	0.003	0.41	0.005		0.7	0.18		11.86	1.327	20.3	812.5	4563
	4	0.072	0.004	0.45	0.008		0.85	0.22		11.64	1.27	21	1004	5668
	5	0.091	0.005	0.47	0.01		1.01	0.26		11.86	1.669	22.4	1388	7813
	6	0.1	0.007	0.5	0.011		1.12	0.3		11.86	1.432	21.8	1765	9828
	7	0.12	0.008	0.53	0.014		1.17	0.33		11.71	1.013	20.8	2298	12658
	8	0.13	0.012	0.54	0.016		1.18	0.44		11.64	0.818	21.9	2965	15951
NORD2		Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
	1	0.13	0.04	0.47	0.01		1.64	1270		12.09	1.356	22.3	6900	83500
	2	0.16	0.06	2.77	0.01		13.3	1110		11.94	1.786	23.8	4120	53600
	3	0.08	0.05	0.37			1.18	1150		11.85	1.357	20.9	4100	52500
	4	0.07	0.08	0.36	0.01		1.34	1040		11.7	1.34	21.1	4100	52300
	5	0.04	0.06	0.35	0.01		0.68	890		11.93	2.005	22.4	7500	98500
	6	0.03	0.09	0.46			0.87	860		11.93	1.73	21.7	7180	91000
	7	0.1	0.1	0.2		0.8	1.3	900		11.88	1.576	20.9	10350	126000
	8	0.09	0.2	0.32		0.56	0.9	1940		11.85	1.406	21.9	12800	142000
Fraction		mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	pH	mS/cm	C	mg/m2	mg/m2
	1	0.006	0.002	0.02	0		0.071	55		12.05	1.212	22.4	299	3618
	2	0.013	0.004	0.14	0.001		0.65	103.1		11.91	1.689	24.2	477.5	5941
	3	0.016	0.007	0.16			0.7	153		11.81	1.227	20.9	655.2	8216
	4	0.019	0.01	0.17			0.75	198		11.68	1.244	21.3	832.9	10482
	5	0.021	0.013	0.19			0.78	236.6		11.84	1.604	22.6	1158	14751
	6	0.022	0.016	0.21			0.82	273.9		11.87	1.457	21.8	1469	18694
	7	0.026	0.021	0.22			0.88	312.9		11.69	0.977	21.2	1918	24154
	8	0.03	0.029	0.23			0.92	396.9		11.72	0.999	21.9	2472	30307

NORW1				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	11.79		1.22	295.6	0.06	68.5	0.03	0.51	8.09	0.82	0.43	2.94	3.33
2	11.83		1.25	571.3	0.12	71.5	0.06	0.55	9.46	0.4	0.35	3.34	3.49
3	11.8		1.34	802.1	0.1	74.5	0.03	0.56	10.1	0.51	0.18	3.22	3.54
4	11.81		1.28	905	0.12	71.1	0.03	0.49	9.25	0.5	0.17	2.83	3.6
5	11.84		1.61	1107	0.1	106.5	0.02	0.69	10.6	0.69	0.12	3.52	4.5
6	11.52		1.28	1153	0.18	79.1	0.04	0.51	7.7	0.86	0.14	2.45	3.26
7	11.75		1.1	1121	0.14	70		0.35	6.9	1.6		2.1	0.78
8	11.57		0.78	1126	0.14	49		0.27	6.5	1.7		1.6	0.68
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		0.25	12.8	0.003	2.97	0.001	0.022	0.35	0.036	0.019	0.13	0.14
2	24		1	37.6	0.008	6.06	0.004	0.046	0.76	0.053	0.034	0.27	0.3
3	54		2.25	72.3	0.012	9.29	0.005	0.07	1.2	0.075	0.042	0.41	0.45
4	96		4	111.5	0.017	12.4	0.007	0.091	1.6	0.097	0.049	0.53	0.6
5	218		9.08333	159.5	0.022	17	0.007	0.12	2.06	0.13	0.054	0.69	0.8
6	384		16	209.5	0.029	20.4	0.009	0.14	2.39	0.16	0.06	0.79	0.94
7	864		36	258.1	0.036	23.4		0.16	2.69	0.23		0.88	0.98
8	1536		64	306.9	0.042	25.6		0.17	2.97	0.31		0.95	1
NORW2				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	**EH (mV)**	**K20 (mS/cm)**	µg/l	µg/l	µg/l	µg/l	**µg/l**	µg/l	µg/l	**µg/l**	µg/l	µg/l
1	11.80		1.22	288.3	0.37	117.8	0.1	0.54	36.1	0.76	0.24	19.1	3.75
2	11.83		1.24	495.9	0.42	116.1	0.02	0.52	39.9	0.5	0.23	18.9	3.97
3	11.82		1.4	783	0.57	117.4	0.08	0.6	45.1	0.4	0.2	19.8	4.32
4	11.82		1.31	830.3	0.65	107.1	0.05	0.61	42.3	0.39	0.15	18.1	4.05
5	11.85		1.69	1065	0.45	152.1	0.06	0.7	49.9	0.82	0.21	23.9	4.66
6	11.60		1.49	1305	0.62	130.6	0.08	0.58	48.9	1.65	0.25	21	4.23
7	11.77		1.13	1218	0.64	107	0.03	0.36	33	1.9		13.8	0.46
8	11.62		0.87	1299	0.72	82	0.02	0.27	29	2.3		10.1	0.37
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		**0.25**	12.5	0.016	5.1	0.004	**0.023**	1.56	0.033	**0.01**	0.83	0.16
2	24.00		1	34	0.034	10.1	0.005	0.046	3.29	0.055	0.02	1.65	0.33
3	54.00		2.25	67.9	0.059	15.2	0.009	0.072	5.25	0.072	0.029	2.51	0.52
4	96.00		4	103.9	0.087	19.9	0.011	0.098	7.08	0.089	0.036	3.29	0.7
5	218.00		9.08333	150	0.11	26.5	0.013	0.13	9.24	0.12	0.045	4.33	0.9
6	384.00		16	206.6	0.13	32.1	0.017	0.15	11.4	0.2	0.055	5.24	1.08
7	864.00		36	259.4	0.16	36.7	0.018	0.17	12.8	0.28		5.84	1.1
8	1536.00		64	315.7	0.19	40.3	0.019	0.18	14	0.38		6.27	1.12

NORW1	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
1	0.07	0.2	0.6	0.04		1.9	640		11.78	1.287	20.3	3630	5650
2	0.04	0.28	3.03	0.04		10.5	680		11.84	1.344	21.2	1680	3260
3	0.03	0.35	0.44	0.01		1.55	700		11.81	1.448	21.8	1870	3480
4	0.08	0.33	0.99	0.03		2.99	660		11.77	1.358	20.7	2160	3960
5	0.02	0.36	0.26	0.03		0.86	580		11.79	1.849	21	5130	8500
6	0.01	0.49	0.34		0.01	1.77	600		11.63	1.721	22	5120	8250
7	0.07	0.48	0.33	0.06	0.16	4.8	630		11.82	1.519	21.7	7550	11650
8	0.12	0.7	0.29	0.03	0.3	3	990		11.7	1.129	22.8	9000	13750
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	pH	mS/cm	C	mg/m2	mg/m2
1	0.003	0.009	0.026	0.002		0.082	27.7					157.3	244.8
2	0.005	0.021	0.16	0.003		0.54	57.2		11.71	1.726	22.6	230.1	386.1
3	0.006	0.036	0.18	0.004		0.61	87.5		11.6	1.727	22	311.1	536.9
4	0.01	0.05	0.22	0.005		0.74	116.1		11.72	1.568	23	404.7	708.5
5	0.01	0.066	0.23	0.007		0.77	141.3		11.85	1.401	22	627	1077
6	0.011	0.087	0.25			0.85	167.3		11.91	1.692	22.2	848.9	1434
7	0.014	0.11	0.26			1.06	194.6		11.78	1.387	22.2	1176	1939
8	0.019	0.14	0.27			1.19	237.5		11.75	1.222	22.8	1566	2535
NORW2	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
1	0.15	0.7	0.55	0.01		2.76	730		11.79	1.219	20.5	3280	6950
2	0.28	1	0.34	0.01		3.06	820		11.83	1.254	21	1820	4650
3	0.05	1.45	0.35	0.01		2.92	920		11.8	1.34	21.9	2360	5500
4	0.08	1.27	0.18	0.01		2.48	770		11.81	1.275	20.8	2650	6050
5	0.12	1.35	0.22			2.68	660		11.84	1.614	21.1	5450	11600
6	0.11	1.94	0.42	0.02	0.09	2.78	980		11.52	1.279	22.3	5420	10700
7	0.07	2	0.26		0.18	2.3	700		11.75	1.097	21.7	7420	14250
8	0.16	2.8	0.37	0.03	0.44	3.9	1050		11.57	0.784	23.1	8150	15250
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	pH	mS/cm	C	mg/m2	mg/m2
1	0.007	0.03	0.024	0		0.12	31.6		11.8	1.224	20.9	142.1	301.2
2	0.019	0.074	0.039	0.001		0.25	67.2		11.83	1.242	21.1	221	502.7
3	0.021	0.14	0.054	0.001		0.38	107		11.82	1.399	22.1	323.3	741
4	0.024	0.19	0.062	0.002		0.49	140.4		11.82	1.311	20.9	438.1	1003
5	0.029	0.25	0.071			0.6	169		11.85	1.69	21.4	674.3	1506
6	0.034	0.33	0.089			0.72	211.5		11.6	1.491	22.2	909.1	1970
7	0.037	0.42	0.1			0.82	241.8		11.77	1.131	21.8	1231	2587
8	0.044	0.54	0.12			0.99	287.3		11.62	0.868	23.1	1584	3248

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORH1				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	12.06		1.25	273.1	0.01	97.1	0.15	0.83	5.74	4.54	0.63	3.14	1.7
2	11.87		1.25	464.3	0.01	127.9	0.13	0.83	6.28	2.13	0.51	1.56	1.47
3	11.78		1.19	578.6		122.9	0.1	0.7	5.53	1.6	0.44	1.12	1.12
4	11.52		1.19	635.3		118.2	0.07	0.7	4.83	1.38	0.48	1.01	1.02
5	11.85		1.59	861.5	0.03	169.3	0.03	0.85	5.64	1.48	0.44	1.08	1.11
6	11.82		1.42	1005		154.9	0.04	0.75	4.46	1.45	0.44	0.9	0.99
7	11.76		1.3	1311		135.4	0.02	0.86	4.29	2.07	0.48	0.99	0.48
8	11.77		1.22	1583	0.26	88		0.7	4	2.1		0.8	0.91
Fraction	Time (hr)	pH	Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6	12.06	0.25	11.8	0	4.21	0.007	0.036	0.25	0.2	0.027	0.14	0.074
2	24	11.87	1	32	0.001	9.75	0.012	0.072	0.52	0.29	0.049	0.2	0.14
3	54	11.78	2.25	57		15.1	0.016	0.1	0.76	0.36	0.068	0.25	0.19
4	96	11.52	4	84.6		20.2	0.02	0.13	0.97	0.42	0.089	0.3	0.23
5	218	11.85	9.08333	121.9		27.5	0.021	0.17	1.21	0.48	0.11	0.34	0.28
6	384	11.82	16	165.4		34.2	0.023	0.2	1.41	0.55	0.13	0.38	0.32
7	864	11.76	36	222.3		40.1	0.023	0.24	1.59	0.63	0.15	0.42	0.34
8	1536	11.77	64	290.9		43.9		0.27	1.77	0.73		0.46	0.38
NORH3				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	12.02		1.19	288.3		85.5	0.08	0.57	4.3	1.66	0.62	0.14	1.37
2	11.91		1.38	336.2		120.6	0.22	0.69	5.27	1.51	0.61	0.23	2.56
3	11.86		1.33	399.4		115.2	0.05	0.64	4.78	1.26	0.51	0.15	2.33
4	11.64		1.27	443.6	0.01	106.6	0.04	0.55	4.21	1.2	0.48	0.13	1.75
5	11.86		1.67	564.2		155.9	0.02	0.7	4.59	1.5	0.41	0.09	2.85
6	11.86		1.43	651.9		140	0.05	0.6	3.65	1.27	0.5	0.12	2.08
7	11.71		1.01	840.1		103.7	0.02	0.48	2.87	1.52	0.48	0.09	2.58
8	11.64		0.82	750	0.08	65		0.31	2.4	1.2		0.04	0.77
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		0.25	12.5		3.71	0.003	0.025	0.19	0.072	0.027	0.006	0.059
2	24		1	27.1		8.93	0.013	0.055	0.41	0.14	0.053	0.016	0.17
3	54		2.25	44.4		13.9	0.015	0.082	0.62	0.19	0.075	0.023	0.27
4	96		4	63.6		18.5	0.017	0.11	0.8	0.24	0.096	0.028	0.35
5	218		9.08333	88		25.3	0.018	0.14	1	0.31	0.11	0.032	0.47
6	384		16	116.3		31.4	0.02	0.16	1.16	0.36	0.14	0.037	0.56
7	864		36	152.7		35.9	0.021	0.18	1.29	0.43	0.16	0.041	0.67
8	1536		64	185.2		38.7		0.2	1.39	0.48		0.043	0.71

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORH1	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	pH	mS/cm	C	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
1	0.44	0.09	4.14	0.11	0.34	9.87	1510		11.43	1.24	22.4	14600	38500
2	0.25	0.11	3.81	0.11	0.49	9.38	1370		11.44	1.08	21.9	8400	23900
3	0.23	0.08	1.23	0.08	0.68	7.17	1080		11.43	0.983	22.8	7700	21600
4	0.22	0.1	1.11	0.08	0.81	4.67	1000		11.55	0.924	21.9	7400	21000
5	0.21	0.12	0.6	0.14	0.65	2.77	1000		11.63	1.39	22.2	15000	42000
6	0.28	0.11	0.81	0.14	0.99	3.64	1030		11.54	1.335	22	14800	41000
7	0.26	0.17	0.58	0.17	1.14	1.74	1170		11.51	1.596	22.8	22800	60500
8	0.27	0.22	0.41	0.1	3	5	2060		11.2	1.81	24.2	29800	76000
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2				mg/m2	mg/m2
1	0.019	0.004	0.18	0.005	0.015	0.43	65.4					632.7	1668
2	0.03	0.009	0.34	0.01	0.036	0.83	124.8					996.7	2704
3	0.04	0.012	0.4	0.013	0.065	1.14	171.6					1330	3640
4	0.049	0.016	0.45	0.016	0.1	1.35	214.9					1651	4550
5	0.059	0.022	0.47	0.023	0.13	1.47	258.3					2301	6370
6	0.071	0.026	0.51	0.029	0.17	1.63	302.9					2942	8147
7	0.082	0.034	0.53	0.036	0.22	1.7	353.6					3930	10768
8	0.094	0.043	0.55	0.04	0.35	1.92	442.9					5222	14062
NORH3	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl				Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l				µg/l	µg/l
1	0.09	0.03	3.47	0.01	0.09	6.79	860					3870	17100
2	0.08	0.02	6.4	0.02	0.21	15.7	980					1800	8450
3	0.1	0.03	1.29	0.01	0.26	5.17	840					1790	8400
4	0.05	0.02	0.92	0.02	0.37	4.65	750					1820	9000
5	0.03	0.01	0.67	0.01	0.19	3.6	720					3880	18100
6	0.1	0.02	0.63	0.02	0.35	4.07	720					3830	17500
7	0.04	0.01	0.57	0.03	0.83	1.79	790					5680	25800
8	0.09	0.02	0.24	0.02	2	0.4	1060					7050	31000
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2				mg/m2	mg/m2
1	0.004	0.001	0.15	0	0.004	0.29	37.3					167.7	741
2	0.007	0.002	0.43	0.001	0.013	0.98	79.7					245.7	1107
3	0.012	0.003	0.48	0.002	0.024	1.2	116.1					323.3	1471
4	0.014	0.004	0.52	0.003	0.04	1.4	148.6					402.1	1861
5	0.015	0.005	0.55	0.003	0.049	1.56	179.8					570.3	2646
6	0.02	0.006	0.58	0.004	0.064	1.73	211					736.2	3404
7	0.021	0.006	0.6	0.005	0.1	1.81	245.3					982.4	4522
8	0.025	0.007	0.61	0.006	0.19	1.83	291.2					1288	5865

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORH5				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	12.09		1.36	367.3		43.4	0.1	0.45	1.7	1.52	0.69	0.27	0.38
2	11.94		1.79	1173		71.9	0.09	0.61	2.4	1.56	0.58	0.25	1.51
3	11.85		1.36	850.8		55.8	0.04	0.53	1.52	0.97	0.53	0.17	0.93
4	11.7		1.34	969.3		57.7	0.03	0.48	1.41	1.01	0.58	0.19	0.87
5	11.93		2.01	1274		90.4	0.04	0.62	1.71	1.43	0.61	0.28	1.28
6	11.93		1.73	1299		86.9	0.01	0.54	1.24	1.24	0.62	0.22	0.68
7	11.88		1.58	1530		73.8	0.02	0.46	0.95	1.48	0.62	0.13	0.18
8	11.85		1.41	1790	0.04	50		0.29	1.1	1.5		0.08	1
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		0.25	15.9		1.88	0.004	0.02	0.074	0.066	0.03	0.012	0.016
2	24		1	66.8		5	0.008	0.046	0.18	0.13	0.055	0.023	0.082
3	54		2.25	103.6		7.41	0.01	0.069	0.24	0.18	0.078	0.03	0.12
4	96		4	145.6		9.91	0.011	0.09	0.3	0.22	0.1	0.038	0.16
5	218		9.08333	200.8		13.8	0.013	0.12	0.38	0.28	0.13	0.05	0.22
6	384		16	257.2		17.6	0.013	0.14	0.43	0.33	0.16	0.06	0.24
7	864		36	323.4		20.8	0.014	0.16	0.47	0.4	0.18	0.065	0.25
8	1536		64	401		23		0.17	0.52	0.46		0.069	0.3
NORH6				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	12.05		1.21	356.6		66.3	0.08	0.44	24.9	1.68	0.74	0.16	
2	11.91		1.69	929.6		136.3	0.1	0.65	26	1.28	0.6	0.13	1.44
3	11.81		1.23	695.7		102.7	0.03	0.48	16.7	0.91	0.54	0.1	0.48
4	11.68		1.24	723.9		107	0.02	0.43	15.7	0.97	0.62	0.1	0.57
5	11.84		1.6	967.8		141.7	0.02	0.48	18.6	1.06	0.51	0.15	0.35
6	11.87		1.46	1006		136.7	0.04	0.42	14.5	1.08	0.54	0.08	0.21
7	11.69		0.98	1307		61	0.03	0.27	13.8	1.37	0.9	0.04	
8	11.72		1	1465	0.06	47		0.21	13	1.6		0.07	0.75
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		0.25	15.5		2.87	0.003	0.019	1.08	0.073	0.032	0.007	
2	24		1	55.7		8.78	0.008	0.047	2.21	0.13	0.058	0.013	
3	54		2.25	85.9		13.2	0.009	0.068	2.93	0.17	0.081	0.017	
4	96		4	117.3		17.9	0.01	0.087	3.61	0.21	0.11	0.021	
5	218		9.08333	159.2		24	0.011	0.11	4.41	0.26	0.13	0.028	
6	384		16	202.8		29.9	0.013	0.13	5.04	0.3	0.15	0.031	
7	864		36	259.4		32.6	0.014	0.14	5.64	0.36	0.19	0.033	
8	1536		64	322.9		34.6		0.15	6.21	0.43		0.036	

ANNEX 7.4 TANK LEACH TEST NEN 7345

NORH5	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	0.11		3.77	0.02	0.68	3.96	1300		5750	73300
2	0.12	0.03	3.95	0.02	1.69	6.88	2030		3720	50200
3	0.11	0.01	1.07	0.02	0.88	4.01	940		3290	44300
4	0.1	0.02	1.15	0.02	1.12	4.22	910		3330	44500
5	0.15	0.03	0.77	0.02	0.74	3.47	870		6650	88000
6	0.1	0.02	0.95	0.02	0.7	3.14	860		6380	80700
7	0.07	0.02	0.75	0.02	0.97	0.76	850		9030	110000
8	0.11	0.03	0.24		3	0.68	1510		10840	121000
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	0.005		0.16	0.001	0.029	0.17	56.3		249.2	3176
2	0.01		0.33	0.002	0.1	0.47	144.3		410.4	5352
3	0.015		0.38	0.003	0.14	0.64	185		552.9	7271
4	0.019		0.43	0.003	0.19	0.83	224.5		697.2	9200
5	0.026		0.46	0.004	0.22	0.98	262.2		985.4	13013
6	0.03		0.51	0.005	0.25	1.11	299.4		1262	16510
7	0.033		0.54	0.006	0.29	1.15	336.3		1653	21277
8	0.038		0.55		0.42	1.18	401.7		2123	26520
NORH6	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	0.15	0.05	3.51	0.02	0.12	4.34	1650		17800	54000
2	0.1	0.04	3.1	0.02	0.21	9.16	1400		9670	31500
3	0.07	0.03	1.19	0.03	0.16	5.39	670		8250	26000
4	0.04	0.04	1.05	0.02	0.15	3.41	640		8820	27500
5	0.15	0.07	0.61	0.02	0.07	4.95	720		18100	54500
6	0.05	0.06	0.9	0.02	0.15	2.97	720		17200	50000
7	0.04	0.09	0.84	0.02	1.07	1.18	1420		25000	68800
8	0.11	0.07	0.32		2.1	0.42	2030		29100	76500
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	0.007	0.002	0.15	0.001	0.005	0.19	71.5		771.3	2340
2	0.011	0.004	0.29	0.002	0.014	0.59	132.2		1190	3705
3	0.014	0.005	0.34	0.003	0.021	0.82	161.2		1548	4832
4	0.016	0.007	0.38	0.004	0.028	0.97	188.9		1930	6023
5	0.022	0.01	0.41	0.005	0.031	1.18	220.1		2714	8385
6	0.024	0.013	0.45	0.006	0.037	1.31	251.3		3460	10552
7	0.026	0.016	0.49	0.007	0.084	1.36	312.9		4543	13533
8	0.031	0.02	0.5		0.17	1.38	400.8		5804	16848

NORH7				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	11.78		1.29	253.8	0.05	39		0.47	7.8	1.36	0.17	0.3	3.05
2	11.84		1.34	358.1	0.05	44.6	0.02	0.5	9.45	0.63	0.26	0.34	3.25
3	11.81		1.45	455.4	0.03	46.9	0.05	0.5	9.66	0.52	0.16	0.22	3.32
4	11.77		1.36	586.1	0.02	45.4	0.06	0.49	9.27	1.31	0.2	0.15	3.03
5	11.79		1.85	687.4	0.04	67.5	0.01	0.68	11	1.16	0.08	0.19	4.44
6	11.63		1.72	783.7		59.4	0.02	0.6	9.14	1.02	0.06	0.19	4.36
7	11.82		1.52	875	0.04	64		0.55	8	2.4		0.12	0.68
8	11.7		1.13	1065	0.05	52		0.38	5.5	2.1		0.1	0.87
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		0.25	11	0.002	1.69		0.02	0.34	0.059	0.007	0.013	0.13
2	24		1	26.5	0.004	3.62		0.042	0.75	0.086	0.019	0.028	0.27
3	54		2.25	46.2	0.006	5.65		0.064	1.17	0.11	0.026	0.037	0.42
4	96		4	71.6	0.007	7.62		0.085	1.57	0.17	0.034	0.044	0.55
5	218		9.08333	101.4	0.008	10.5		0.11	2.05	0.22	0.038	0.052	0.74
6	384		16	135.4		13.1		0.14	2.44	0.26	0.04	0.06	0.93
7	864		36	173.3		15.9		0.16	2.79	0.36		0.065	0.96
8	1536		64	219.5		18.1		0.18	3.03	0.46		0.07	1

NORH9				Al	As	Ba	Cd	Co	Cr	Cu	Mn	Mo	Ni
Fraction	pH	EH (mV)	K20 (mS/cm)	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	11.71		1.73	171.8	0.22	139	0.01	1.43	1.95	3.57	0.39	0.21	4.04
2	11.6		1.73	174.1	0.07	135.8	0.02	0.78	2.52	0.98	0.29	0.22	4.55
3	11.72		1.57	254	0.01	108.1	0.03	0.56	2.54	23.9	0.36	0.26	3.81
4	11.85		1.4	306.9	0.01	98		0.51	1.75	0.6	0.23	0.17	3.28
5	11.91		1.69	390	0.05	129		0.54	1.9	1.3		0.15	0.22
6	11.78		1.39	470	0.03	97	0.01	0.45	1.3	2.2		0.11	0.31
7	11.75		1.22	641	0.03	88	0.02	0.38	0.99	1.8		0.1	0.66
8	11.55		1.03	852	0.06	52		0.21	0.93	2.6		0.09	0.15
Fraction	Time (hr)		Time (days)	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	6		0.25	7.44	0.01	6.02	0	0.062	0.085	0.15	0.017	0.009	0.18
2	24		1	15	0.013	11.9	0.001	0.096	0.19	0.2	0.029	0.019	0.37
3	54		2.25	26	0.013	16.6	0.003	0.12	0.3	1.23	0.045	0.03	0.54
4	96		4	39.3	0.013	20.8		0.14	0.38	1.26	0.055	0.037	0.68
5	218		9.08333	56.2	0.016	26.4		0.17	0.46	1.31		0.044	0.69
6	384		16	76.6	0.017	30.6		0.19	0.52	1.41		0.049	0.7
7	864		36	104.3	0.018	34.4		0.2	0.56	1.49		0.053	0.73
8	1536		64	141.3	0.021	36.7		0.21	0.6	1.6		0.057	0.74

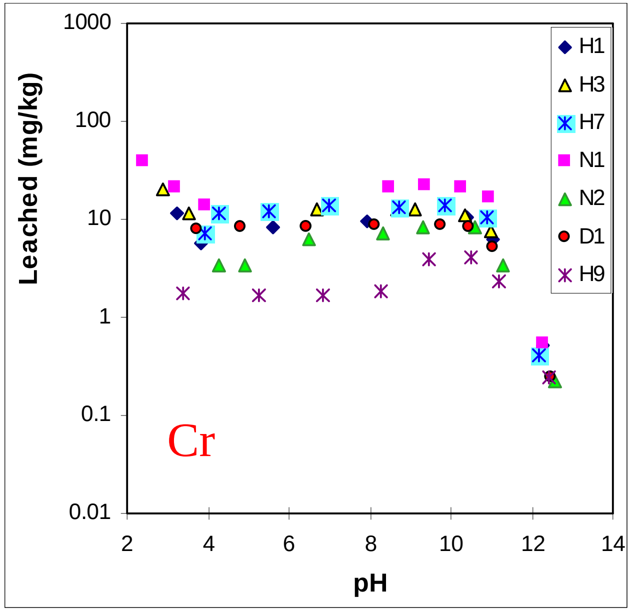
ANNEX 7.4 TANK LEACH TEST NEN 7345

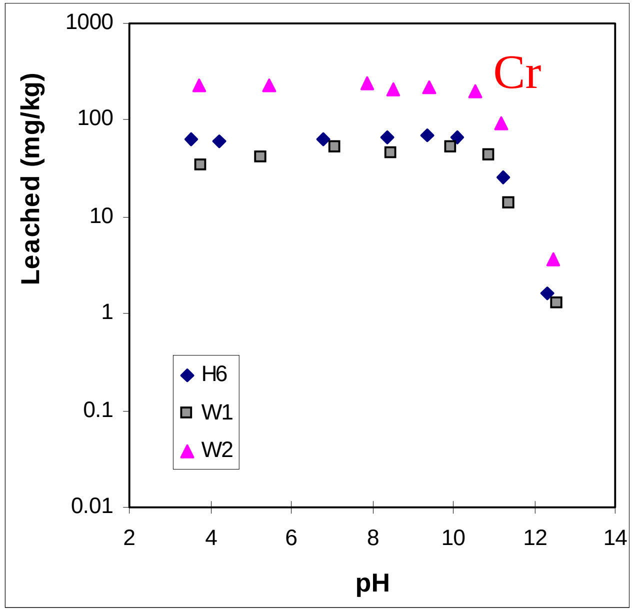
NORH7	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	0.1	0.04	0.73		0.08	2.96	1570		4120	15100
2	0.06	0.04	2.76		0.06	6.33	1580		2450	9550
3	0.04	0.03	0.38	0.01	0.06	2.55	1800		2600	10150
4	0.28	0.03	0.8		0.16	4.48	1890		2620	10150
5	0.03	0.03	0.27		0.03	2.15	1430		5060	19000
6	0.09	0.03	0.37		0.1	2.46	1380		4720	17100
7	0.38	0.03	0.57		0.27	2.2	1260		7050	24800
8	0.1	0.05	0.32	0.03	0.64	1.4	1600		8150	27400
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	0.004	0.002	0.032		0.003	0.13	68		178.5	654.3
2	0.007	0.003	0.15		0.006	0.4	136.5		284.7	1068
3	0.009	0.005	0.17		0.009	0.51	214.5		397.4	1508
4	0.021	0.006	0.2		0.016	0.71	296.4		510.9	1948
5	0.022	0.007	0.21		0.017	0.8	358.4		730.2	2771
6	0.026	0.009	0.23		0.021	0.91	418.2		934.7	3512
7	0.042	0.01	0.25		0.033	1	472.8		1240	4587
8	0.047	0.012	0.27		0.061	1.06	542.1		1593	5774

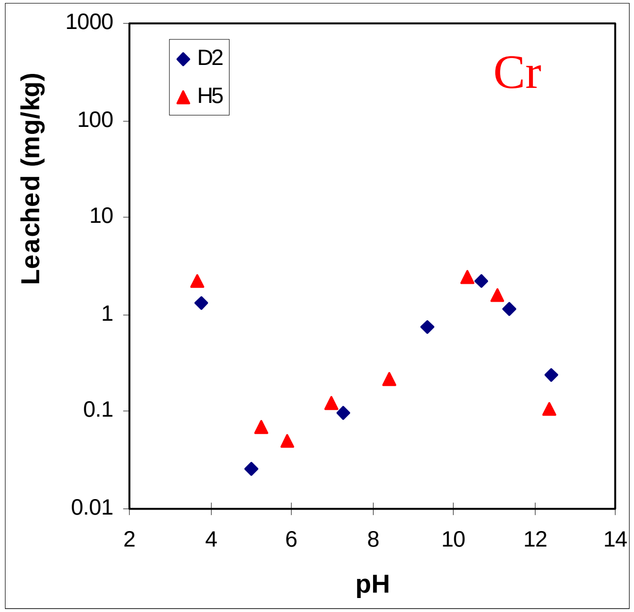
NORH9	Pb	Sb	Sn	Tl	V	Zn	SO4	Cl	Na	K
Fraction	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	0.22	0.14	0.85	0.01	0.57	2.21	2490		7000	23200
2	0.15	0.19	0.42		0.16	2.72	2080		4750	18200
3	0.88	0.26	0.37		0.14	19.4	2000		4450	17200
4	0.08	0.25	0.17	0.01	0.05	0.61	1820		4330	16500
5	0.2	0.16	0.18		0.2	1.1	1550		7770	31000
6	0.3	0.48	0.47		0.24	2.5	1530		7600	28500
7	0.2	0.6	0.32		0.38	2.4	1580		11400	41000
8	0.17	1	0.39	0.06	0.72	2.2	2410		15200	52600
Fraction	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2	mg/m2
1	0.01	0.006	0.037	0	0.025	0.096	107.9		303.3	1005
2	0.016	0.014	0.055		0.032	0.21	198		509.2	1794
3	0.054	0.026	0.071		0.038	1.05	284.7		702	2539
4	0.058	0.036	0.078		0.04	1.08	363.6		889.6	3254
5	0.066	0.043	0.086		0.049	1.13	430.7		1226	4598
6	0.079	0.064	0.11		0.059	1.24	497		1556	5833
7	0.088	0.09	0.12		0.075	1.34	565.5		2050	7609
8	0.095	0.13	0.14		0.11	1.44	669.9		2708	9889

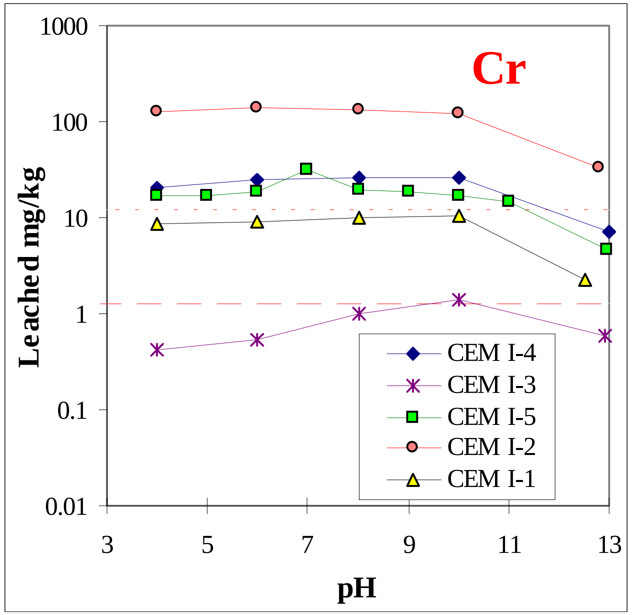
ANNEX 8 GRAPHICAL PRESENTATION OF pH DEPENDENCE LEACHING TEST DATA

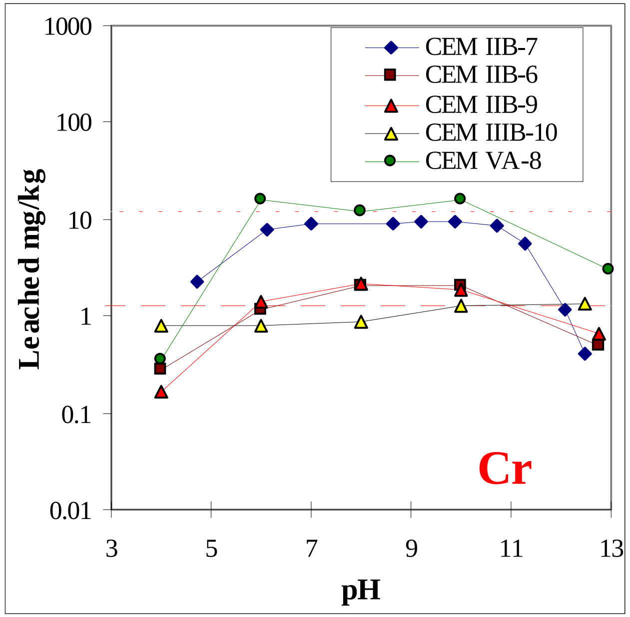
Data for all cements studied in ECRICEM and in addition for comparison dat from Ditec study [13]

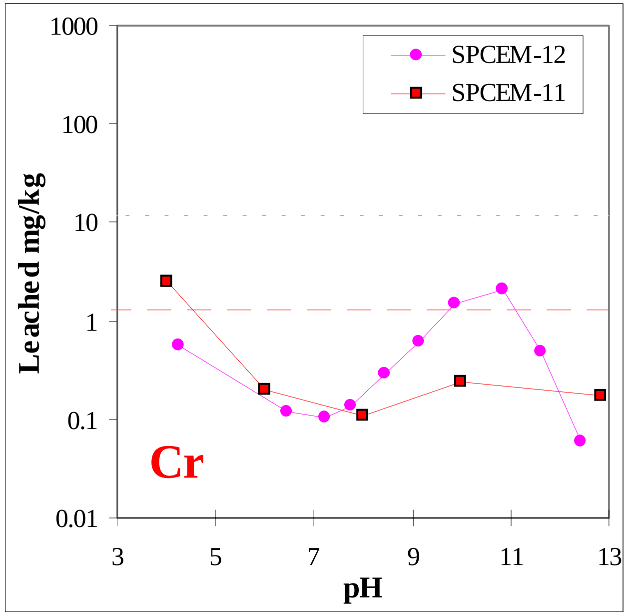


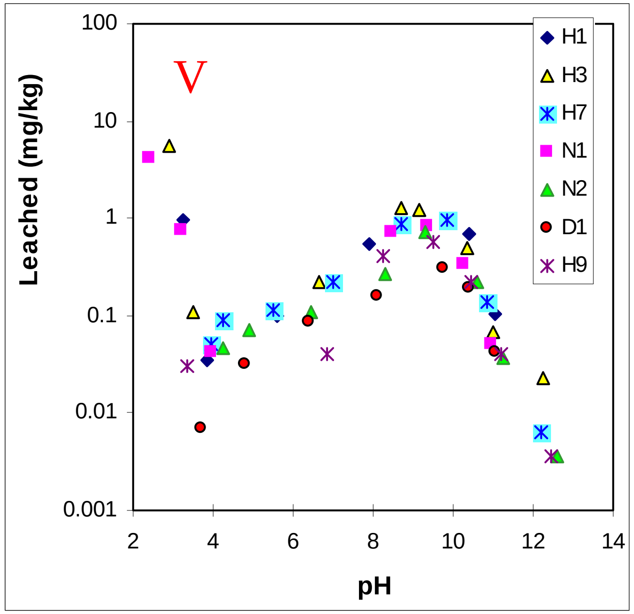


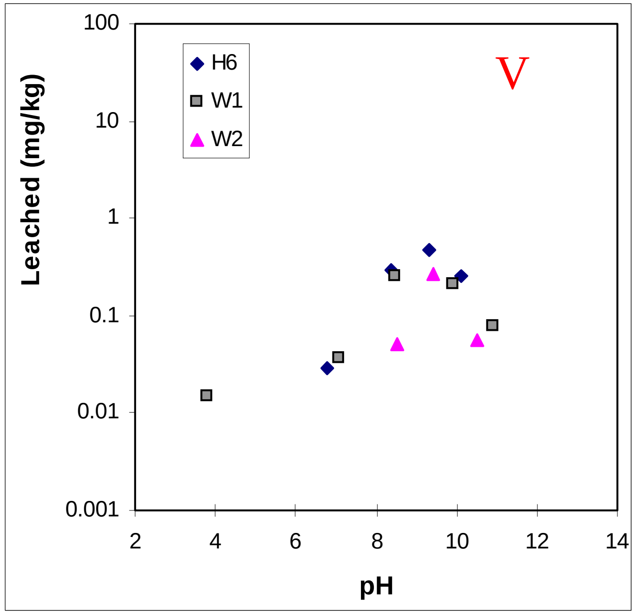


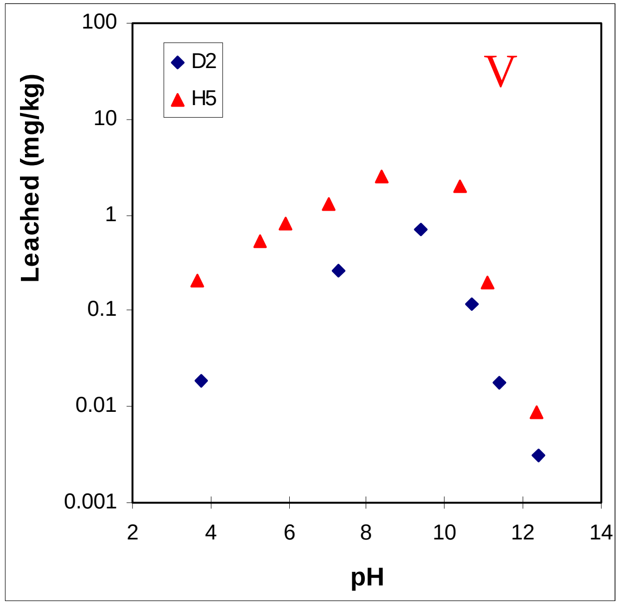


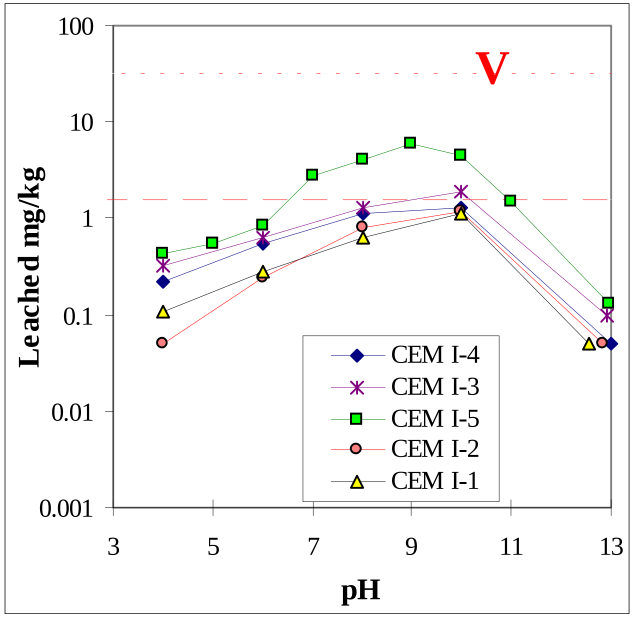


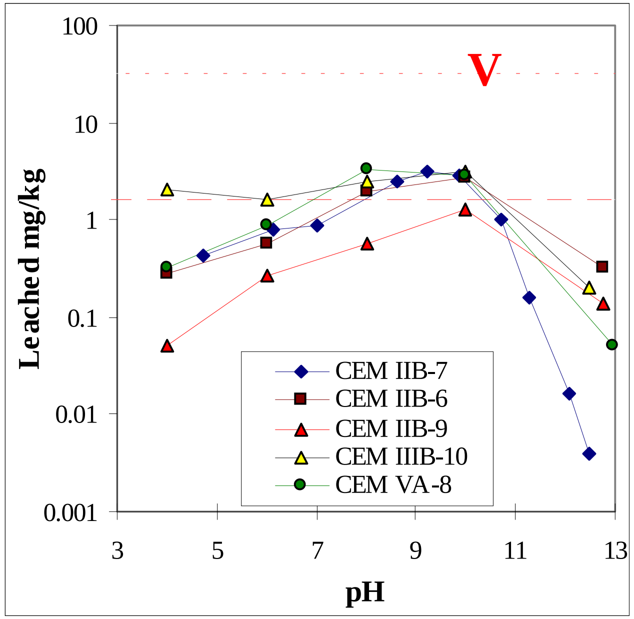


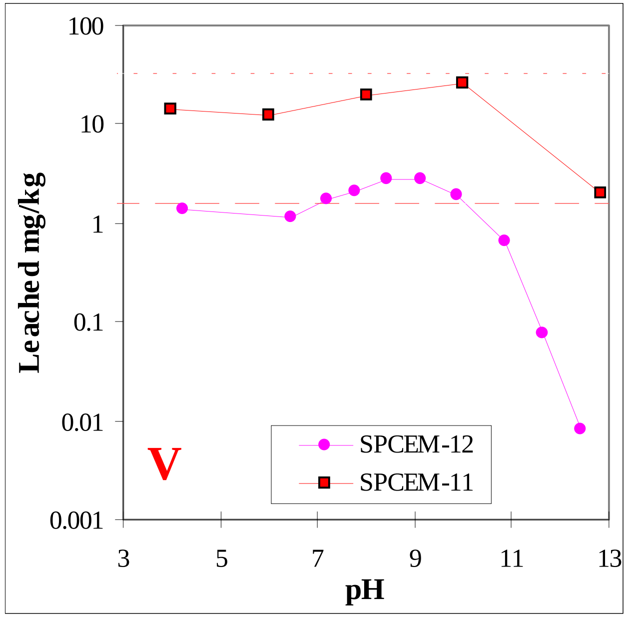

Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14
pH
V
H1
H3
H7
N1
N2
D1
H9

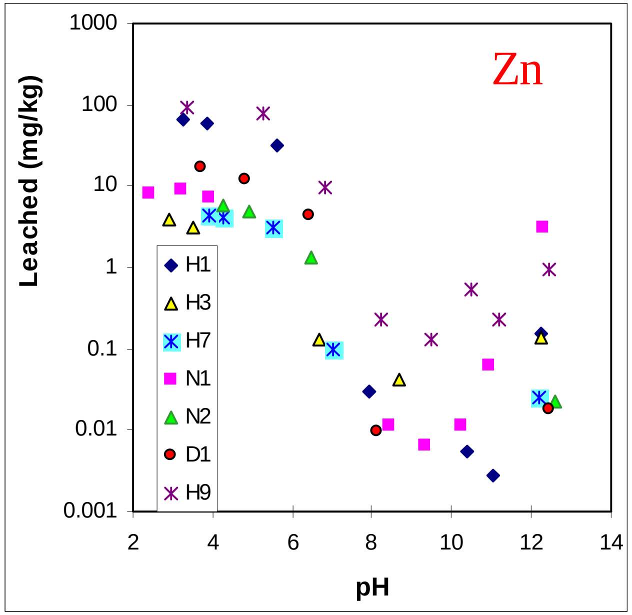

Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14
pH
V
H6
W1
W2

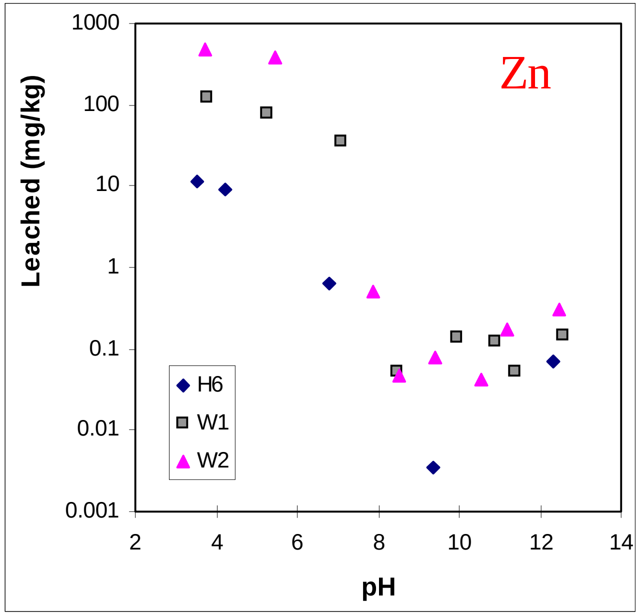

Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14
pH
V
D2
H5

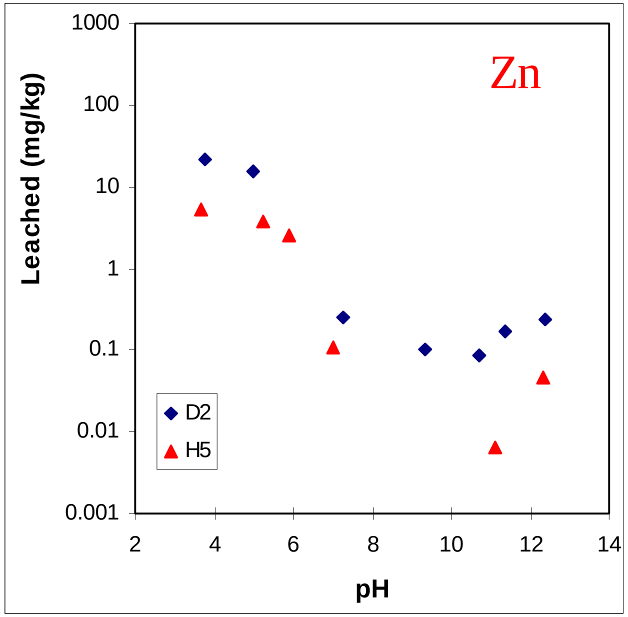

Leached mg/kg
100
10
1
0.1
0.01
0.001
3 5 7 9 11 13
pH
V
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

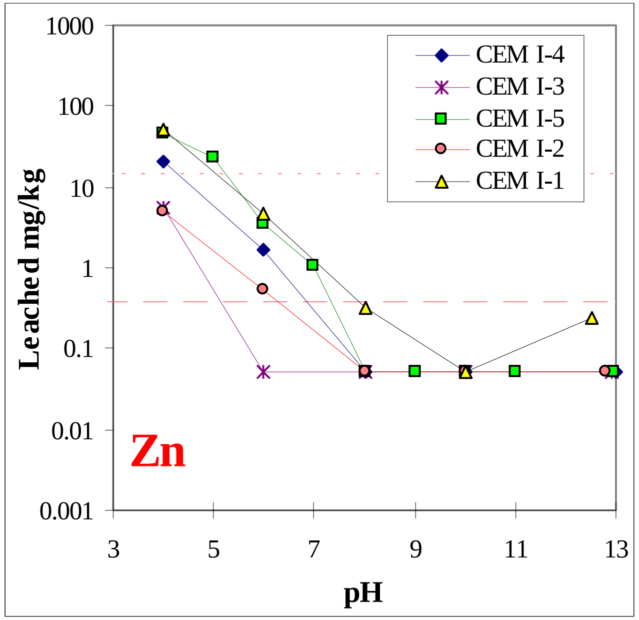

Leached mg/kg
100
10
1
0.1
0.01
0.001
3 5 7 9 11 13
pH
V
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

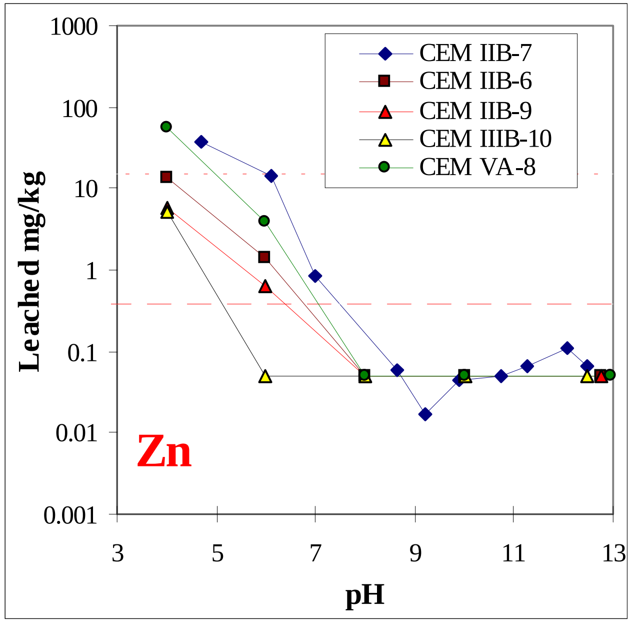

Leached mg/kg
100
10
1
0.1
0.01
0.001
3 5 7 9 11 13
pH
V
SPCEM-12
SPCEM-11

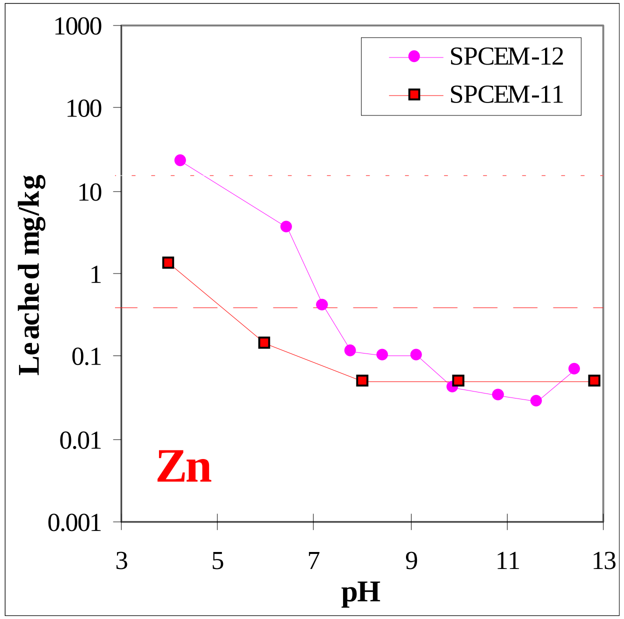

Zn
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

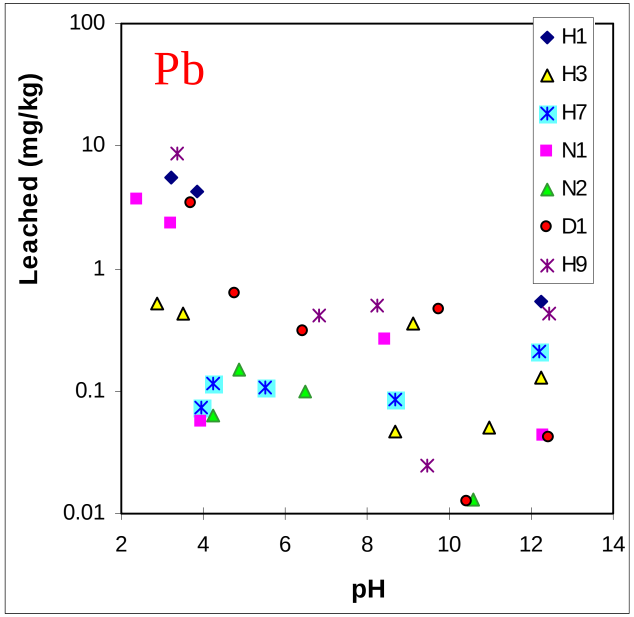

Zn
Leached (mg/kg)
pH
H6
W1
W2

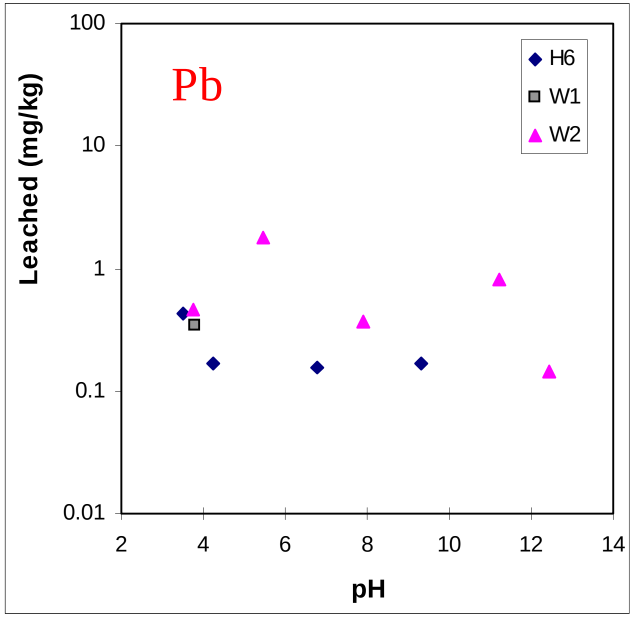

Zn
Leached (mg/kg)
pH
D2
H5

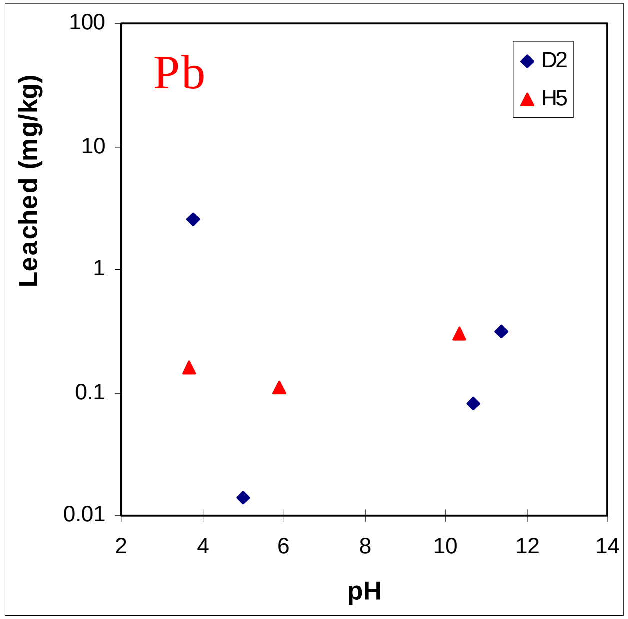

Zn
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

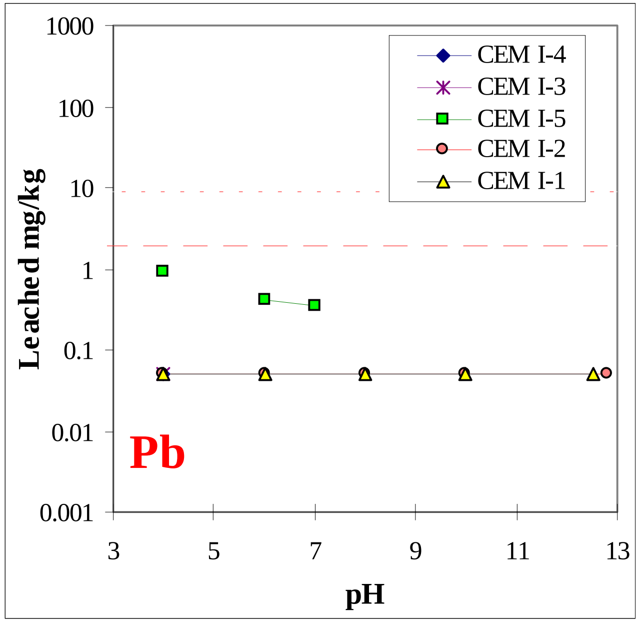

Zn
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

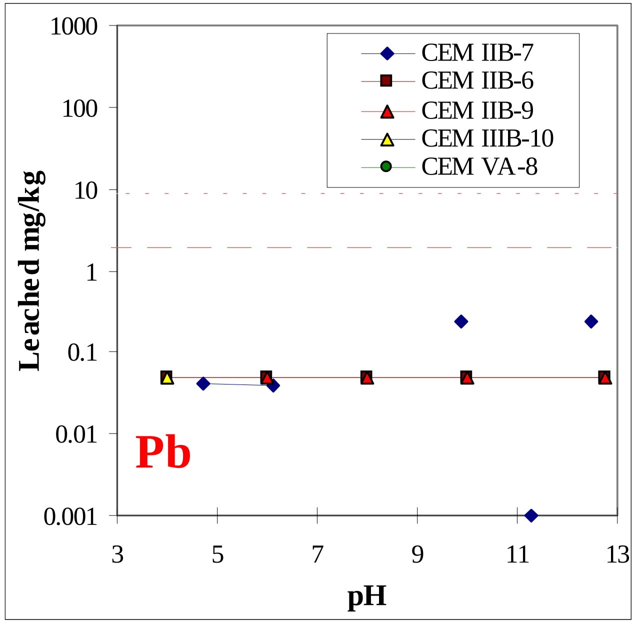

Zn
Leached mg/kg
pH
SPCEM-12
SPCEM-11

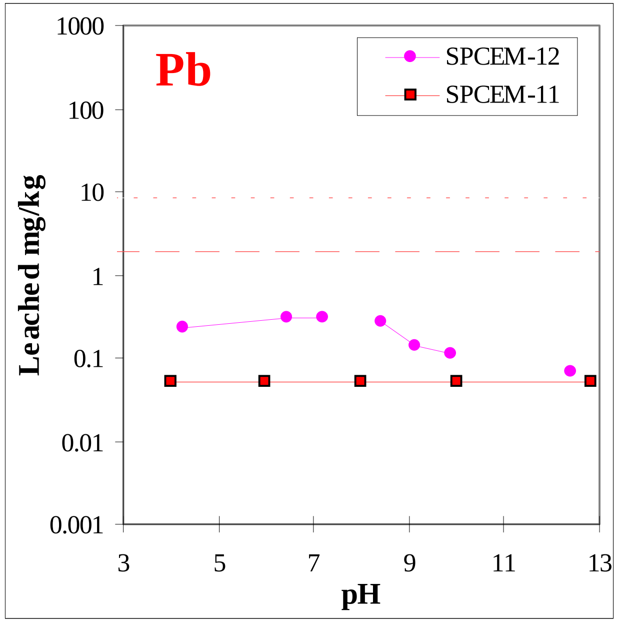

Pb
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
100
10
1
0.1
0.01
2
4
6
8
10
12
14


Pb
Leached (mg/kg)
pH
H6
W1
W2
100
10
1
0.1
0.01
2
4
6
8
10
12
14

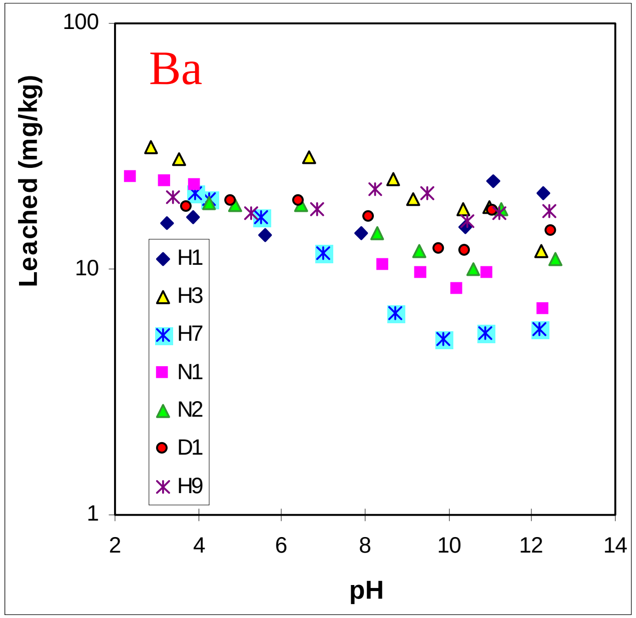

Pb
Leached (mg/kg)
pH
D2
H5
100
10
1
0.1
0.01
2
4
6
8
10
12
14

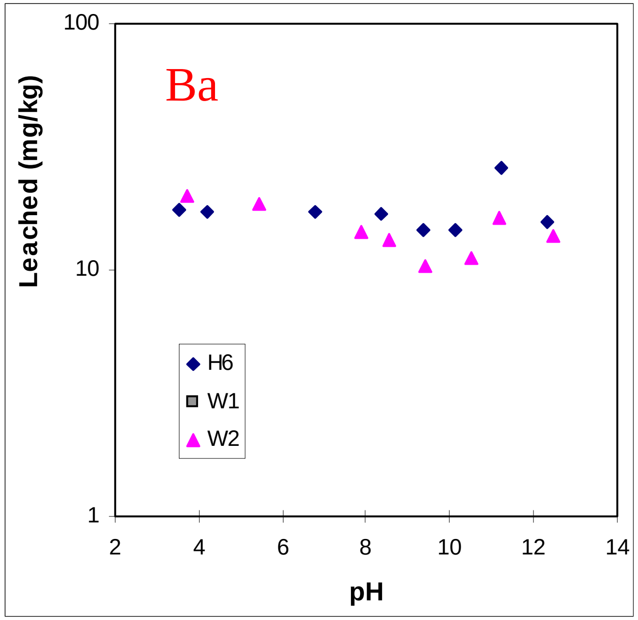

Pb
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

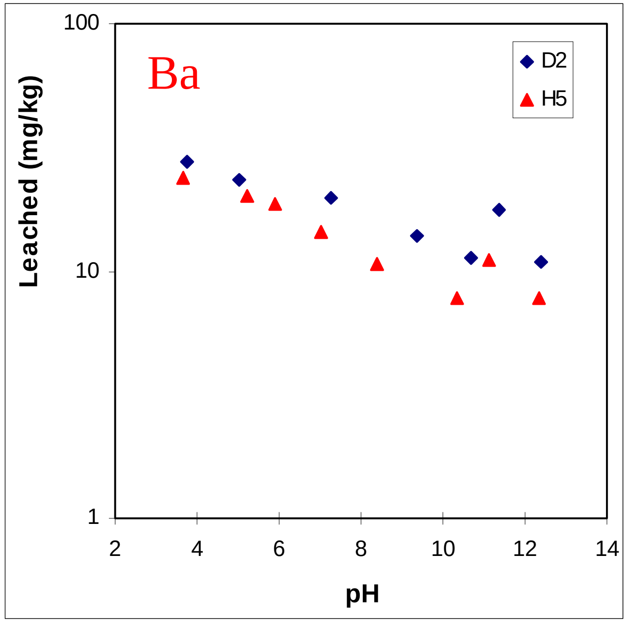

Pb
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

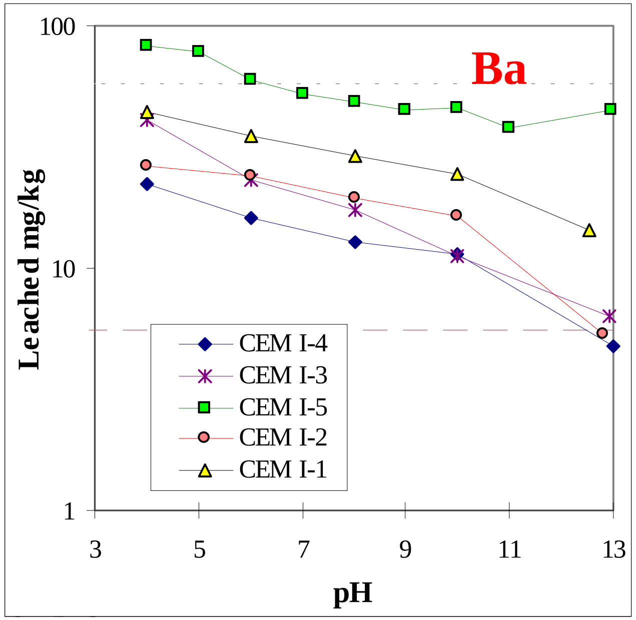

Pb
Leached mg/kg
pH
SPCEM-12
SPCEM-11
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

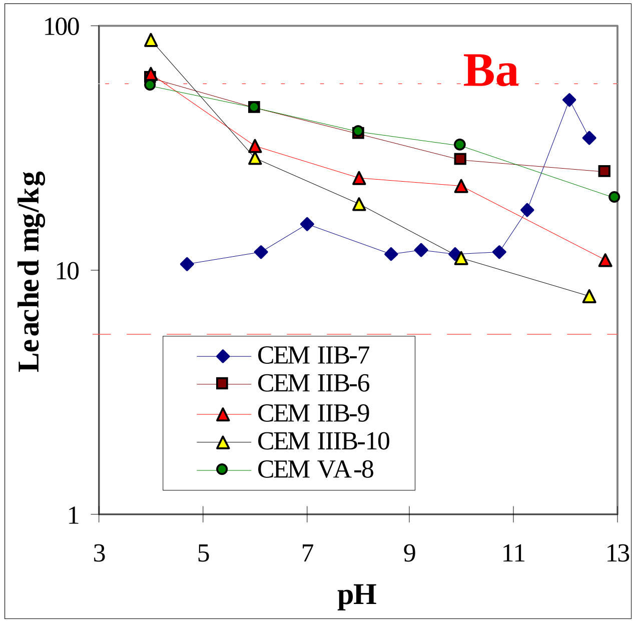
ANNEX 8 GRAPHICAL PH DEPENDENCE TEST DATA

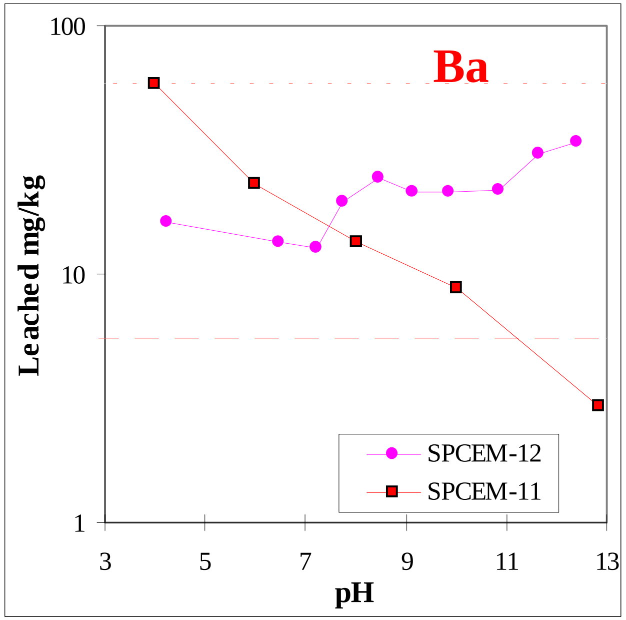


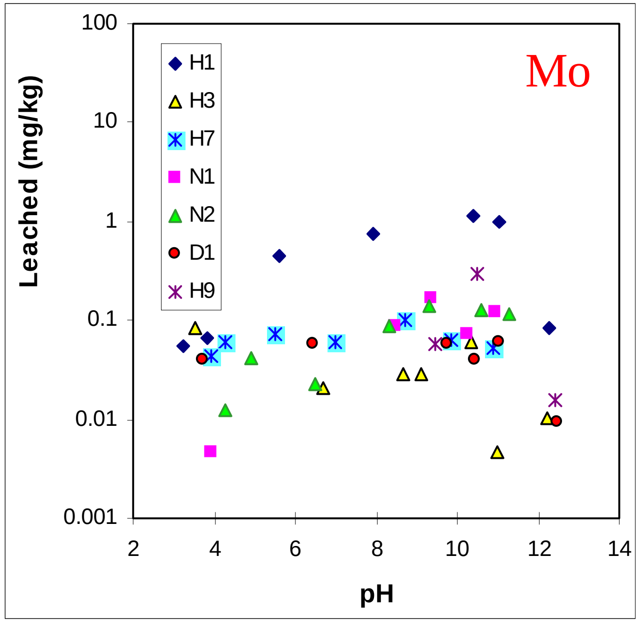


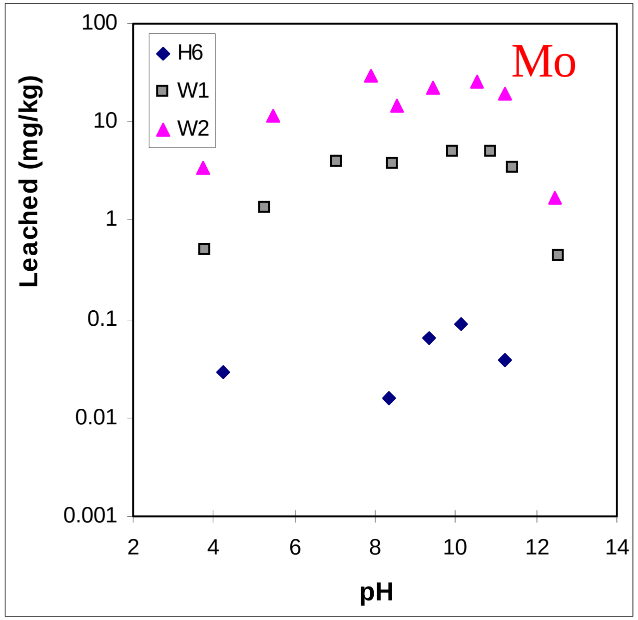


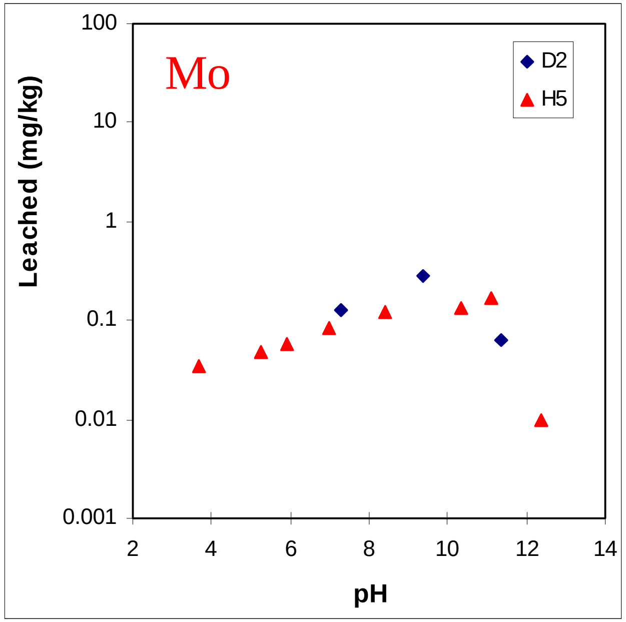


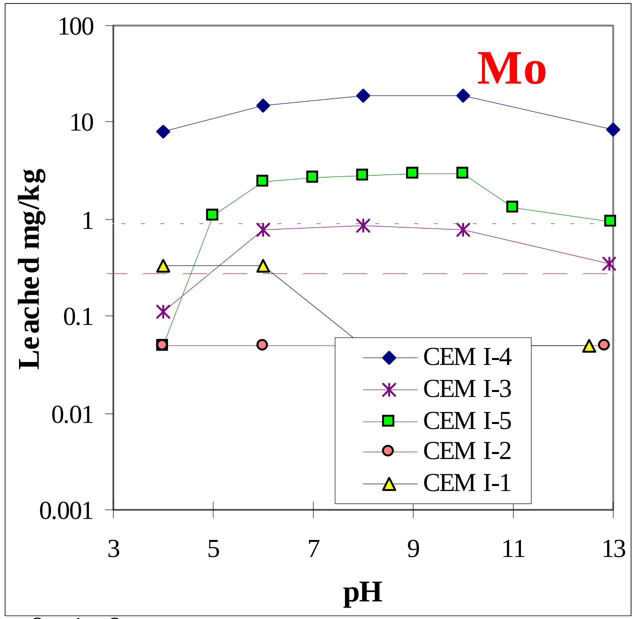


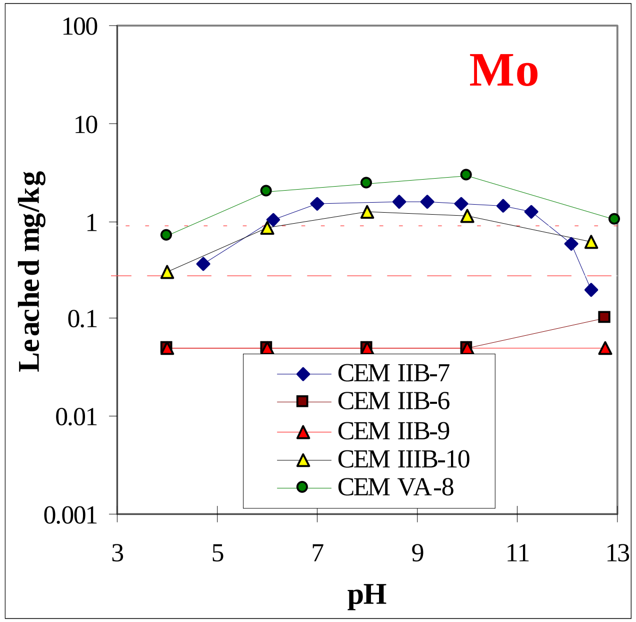


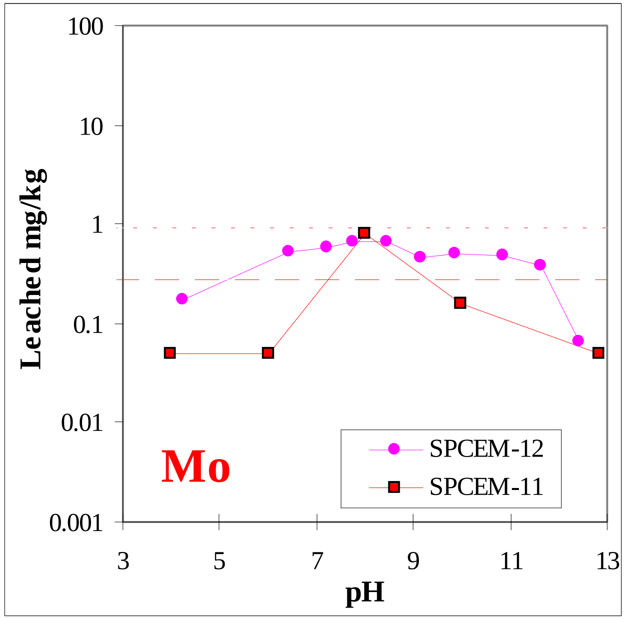

Mo
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14

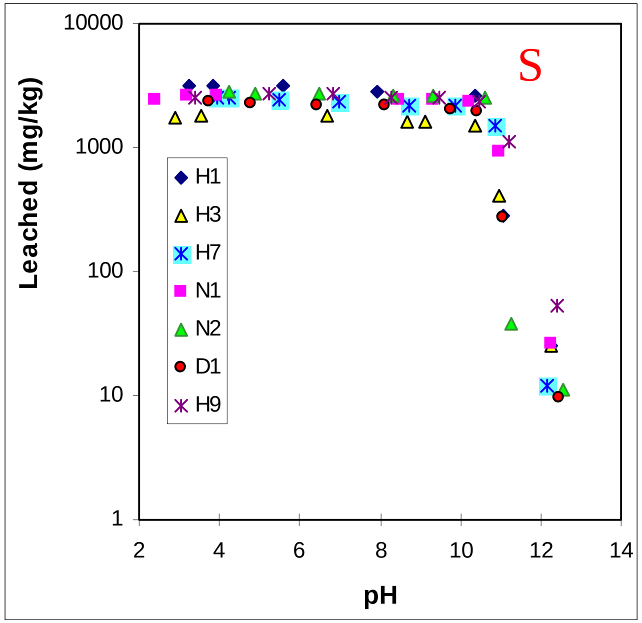

Mo
Leached (mg/kg)
pH
H6
W1
W2
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14

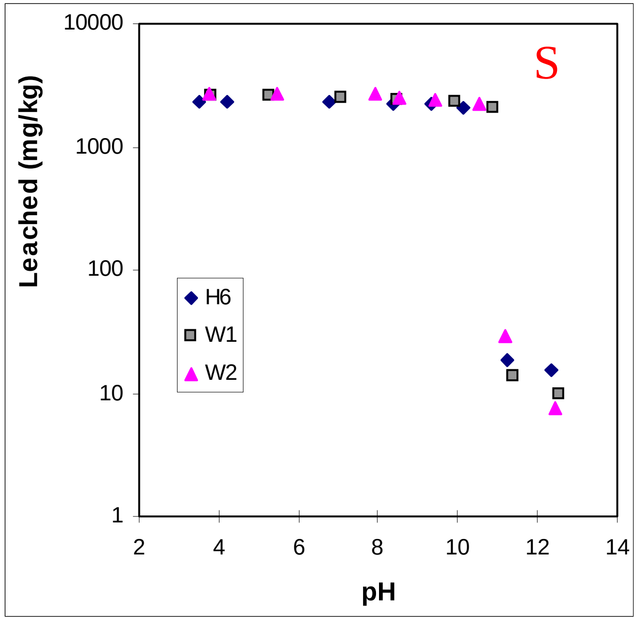

Mo
Leached (mg/kg)
pH
D2
H5
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14

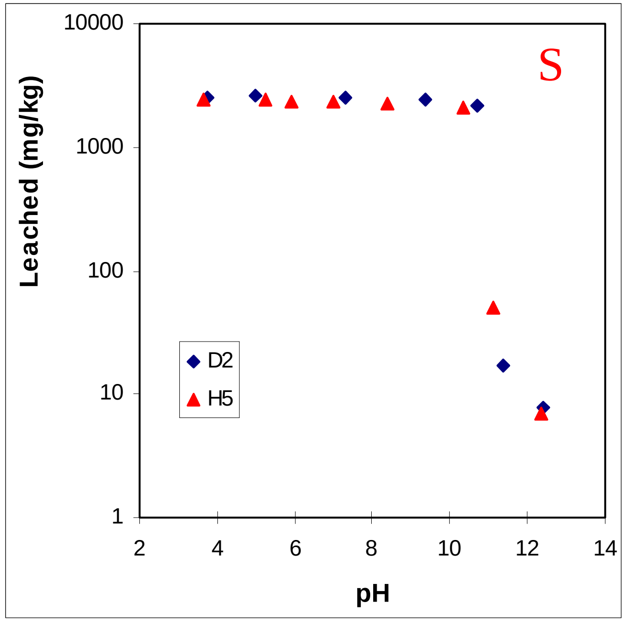

Mo
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

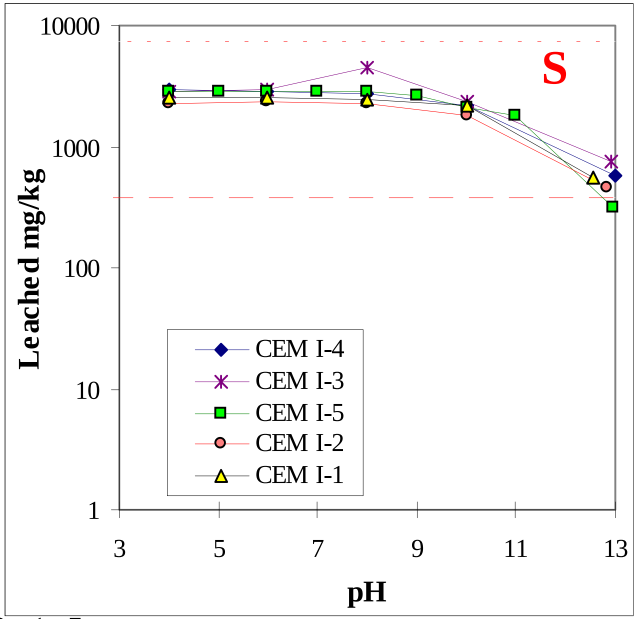

Mo
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

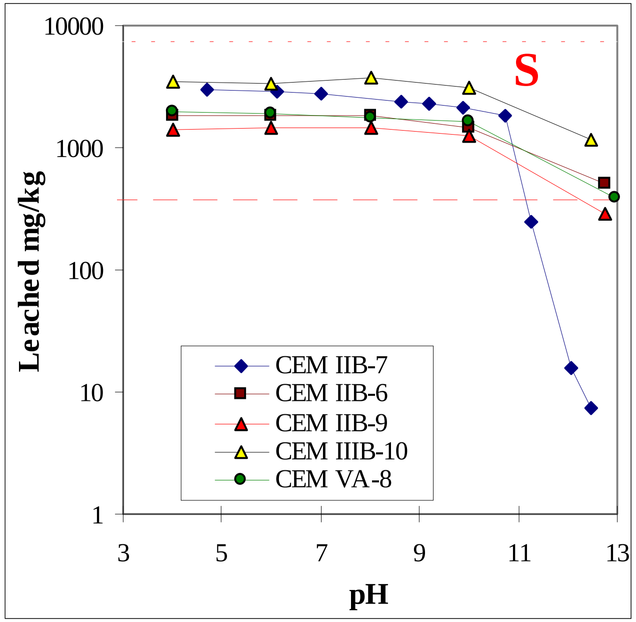

Mo
Leached mg/kg
pH
SPCEM-12
SPCEM-11
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

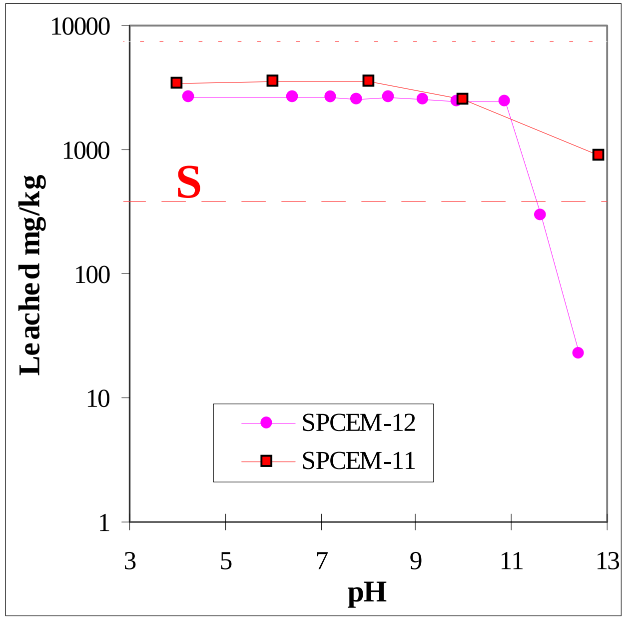

S
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

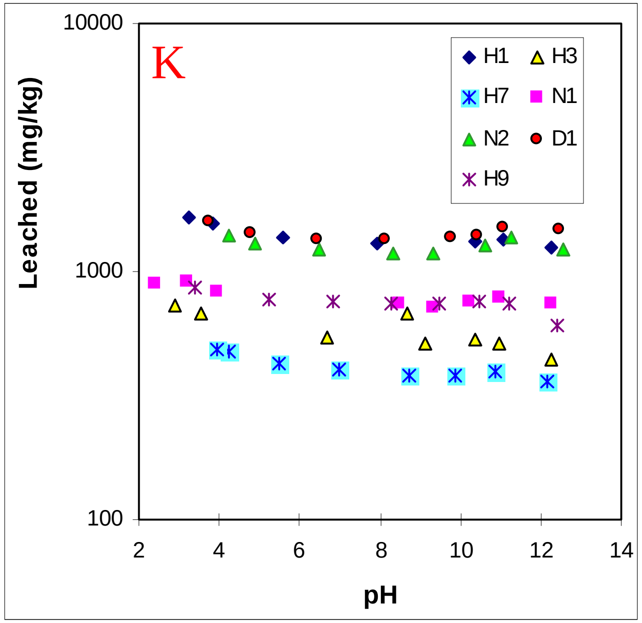

S
Leached (mg/kg)
pH
H6
W1
W2

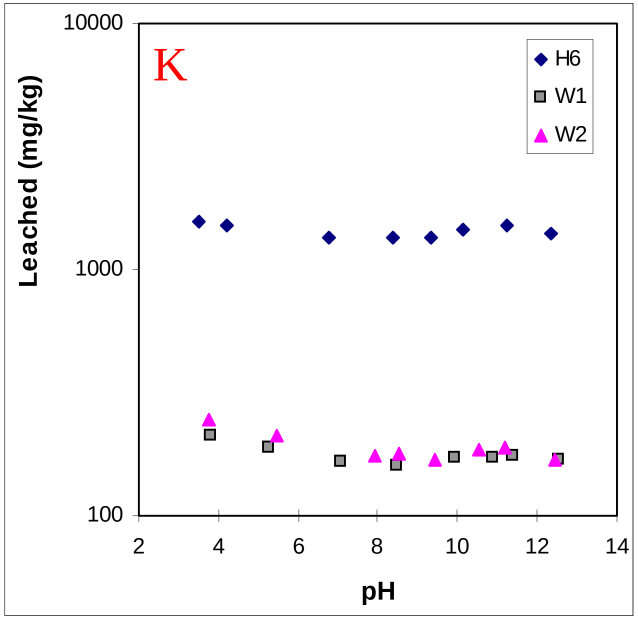

S
Leached (mg/kg)
pH
D2
H5

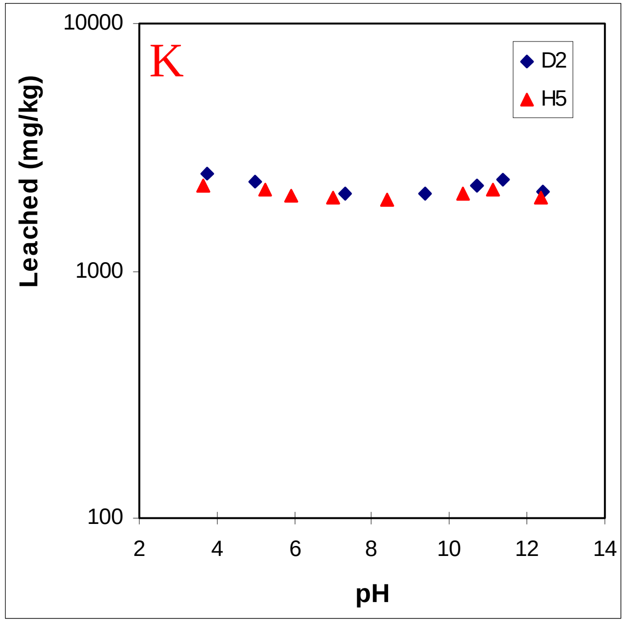

S
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

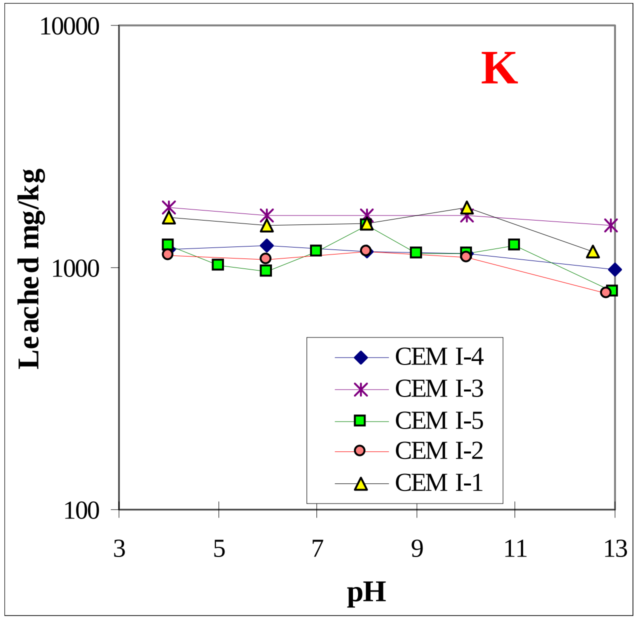

S
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

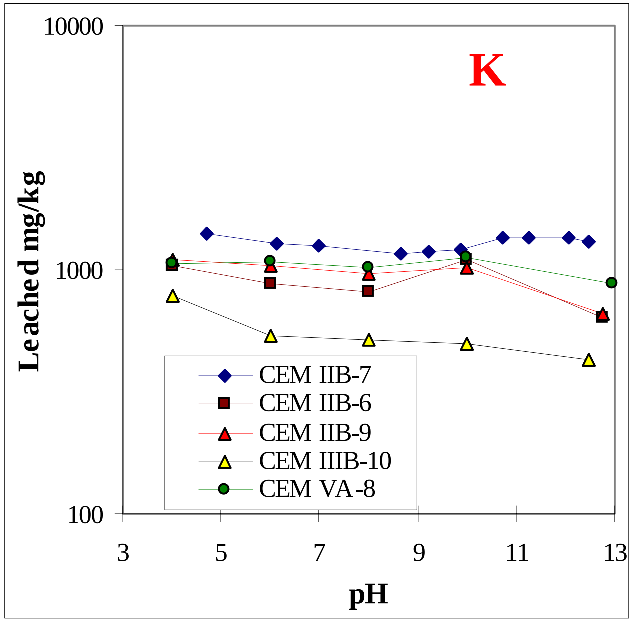

S
Leached mg/kg
pH
SPCEM-12
SPCEM-11

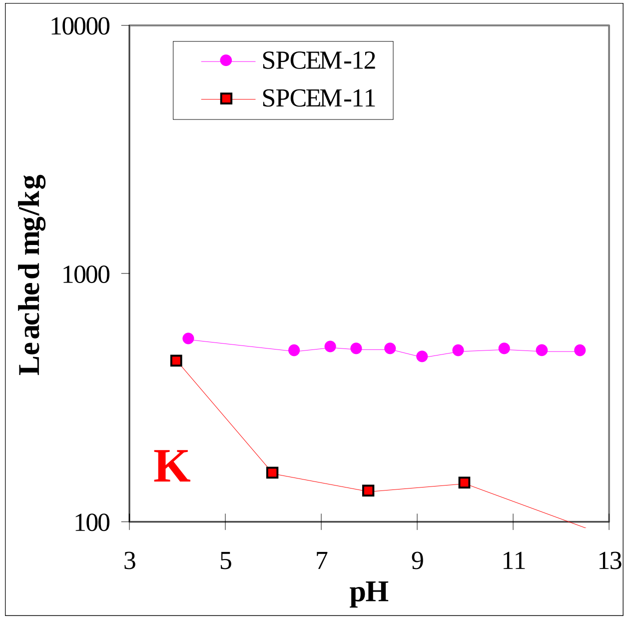

K
H1
H3
H7
N1
N2
D1
H9
Leached (mg/kg)
10000
1000
100
2
4
6
8
10
12
14
pH

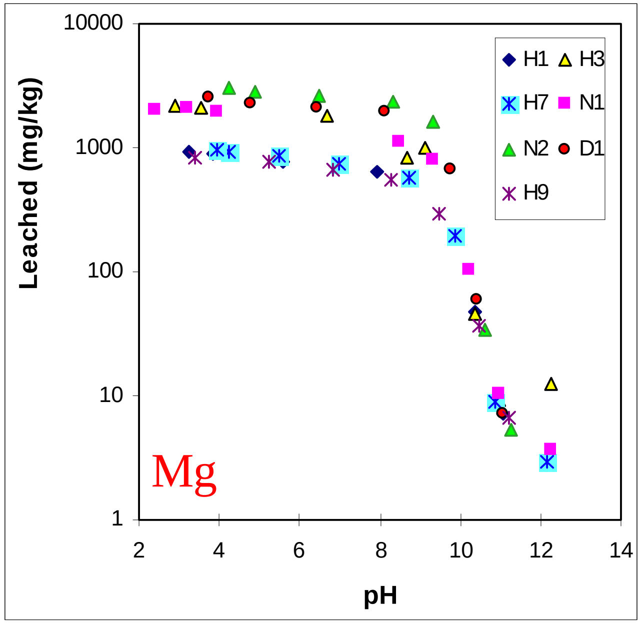

K
H6
W1
W2
Leached (mg/kg)
10000
1000
100
2
4
6
8
10
12
14
pH

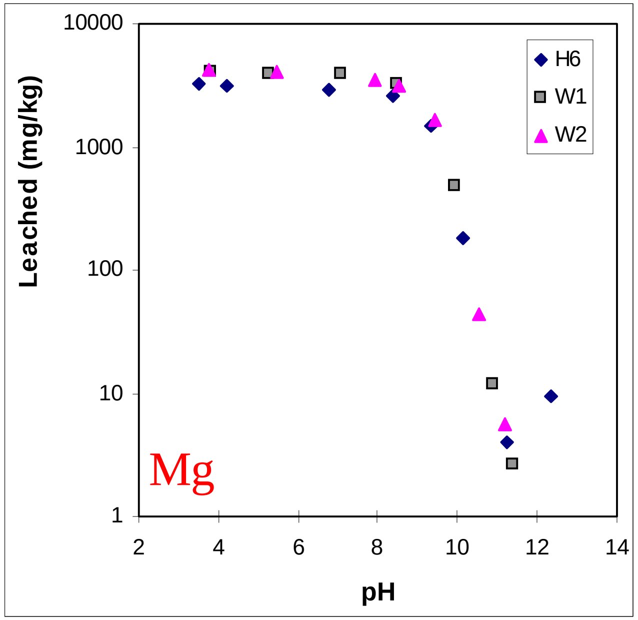

K
D2
H5
Leached (mg/kg)
10000
1000
100
2
4
6
8
10
12
14
pH

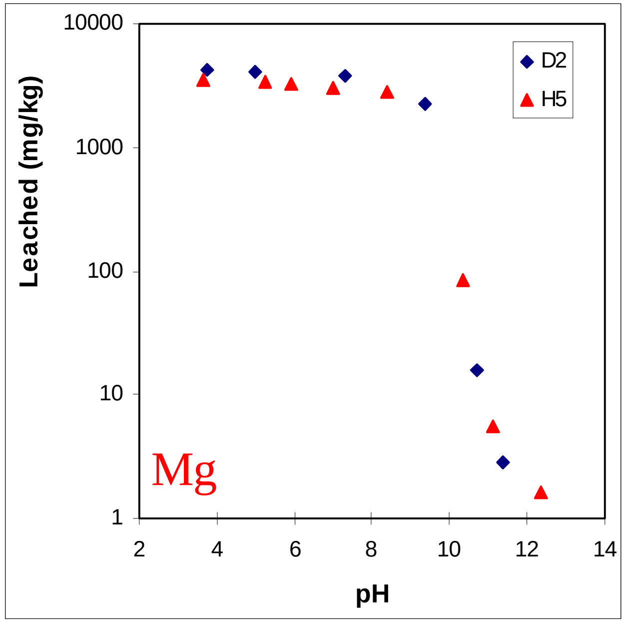

K
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1
Leached mg/kg
10000
1000
100
3
5
7
9
11
13
pH

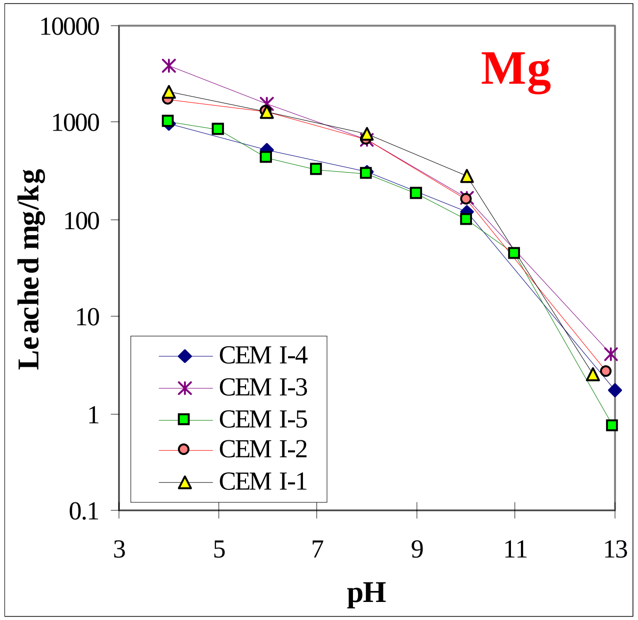

K
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
Leached mg/kg
10000
1000
100
3
5
7
9
11
13
pH

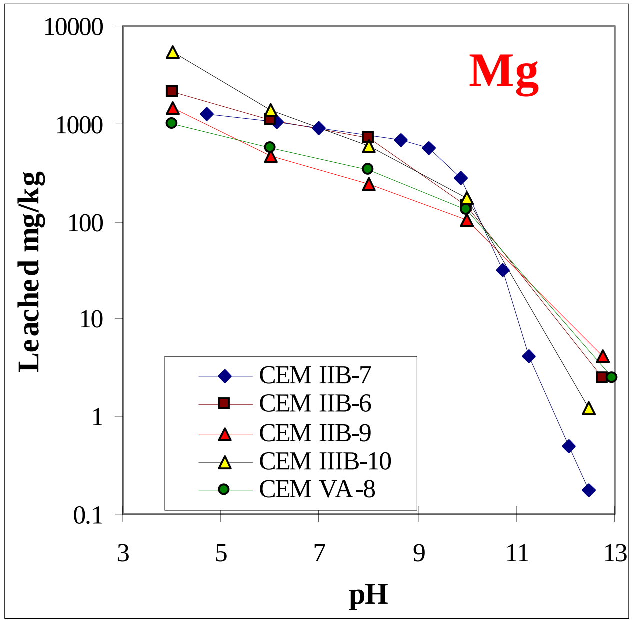

SPCEM-12
SPCEM-11
K
Leached mg/kg
10000
1000
100
3
5
7
9
11
13
pH

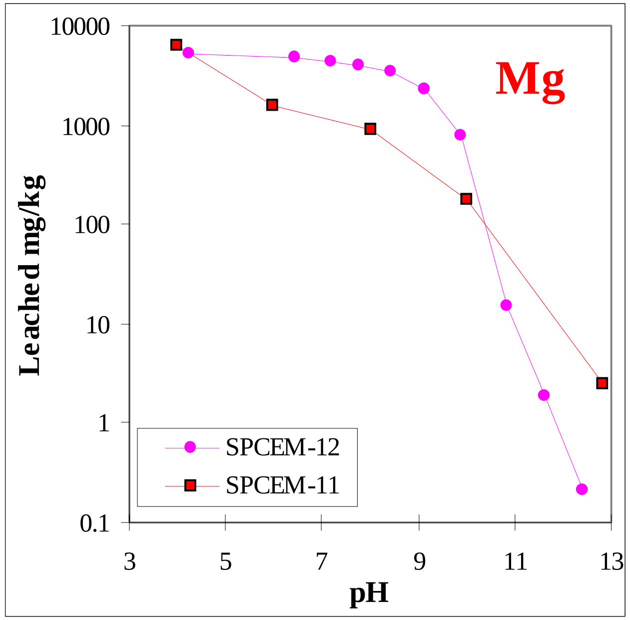

Leached (mg/kg)
10000
1000
100
10
1
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
Mg

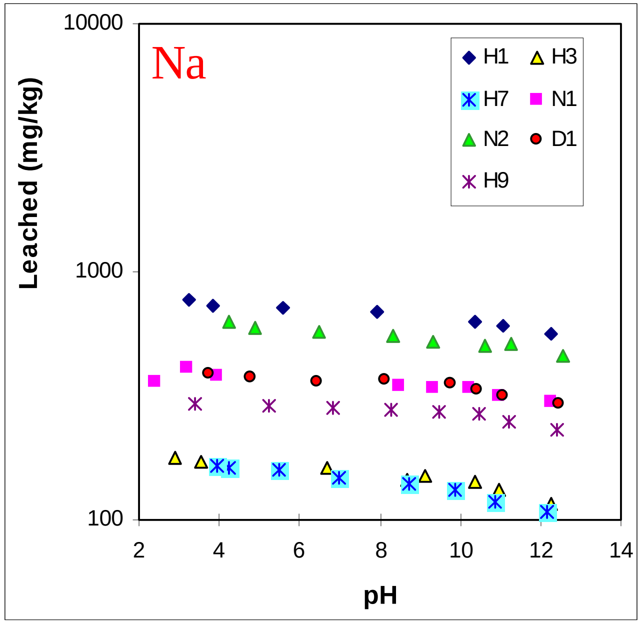

Leached (mg/kg)
10000
1000
100
10
1
2
4
6
8
10
12
14
pH
H6
W1
W2
Mg

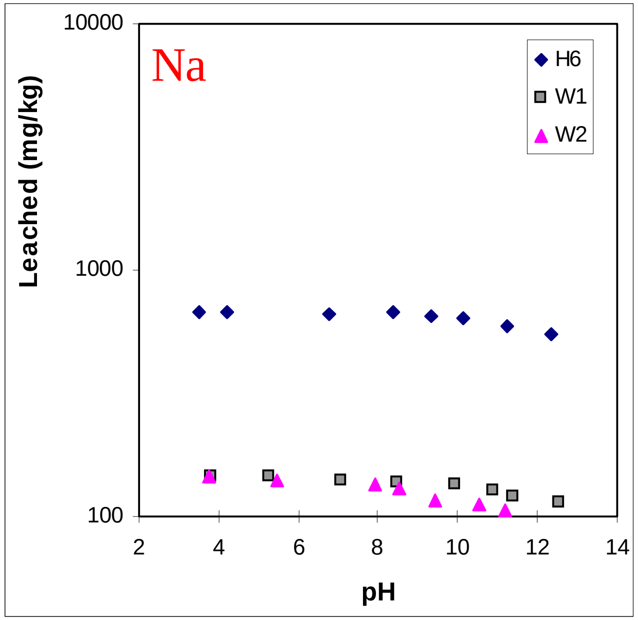

Leached (mg/kg)
10000
1000
100
10
1
2
4
6
8
10
12
14
pH
D2
H5
Mg

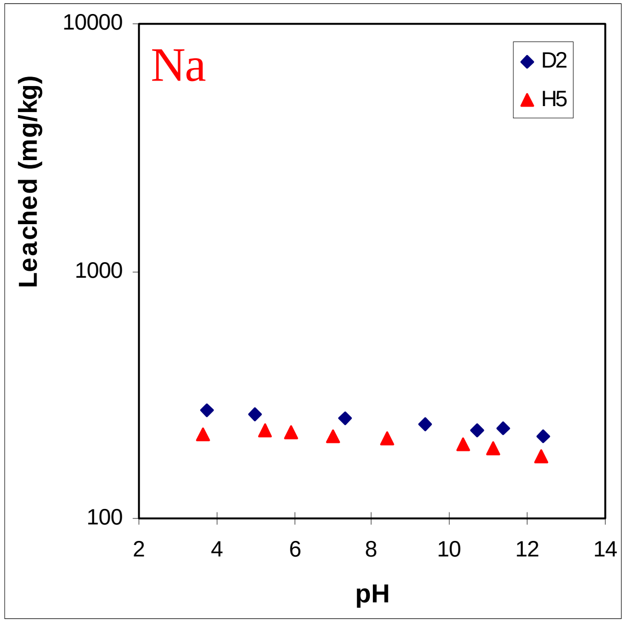

Leached mg/kg
10000
1000
100
10
1
0.1
3
5
7
9
11
13
pH
Mg
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

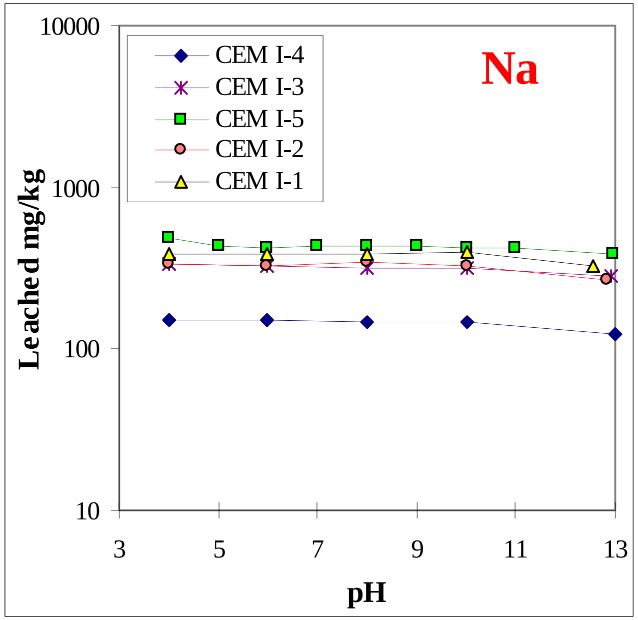

Leached mg/kg
10000
1000
100
10
1
0.1
3
5
7
9
11
13
pH
Mg
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

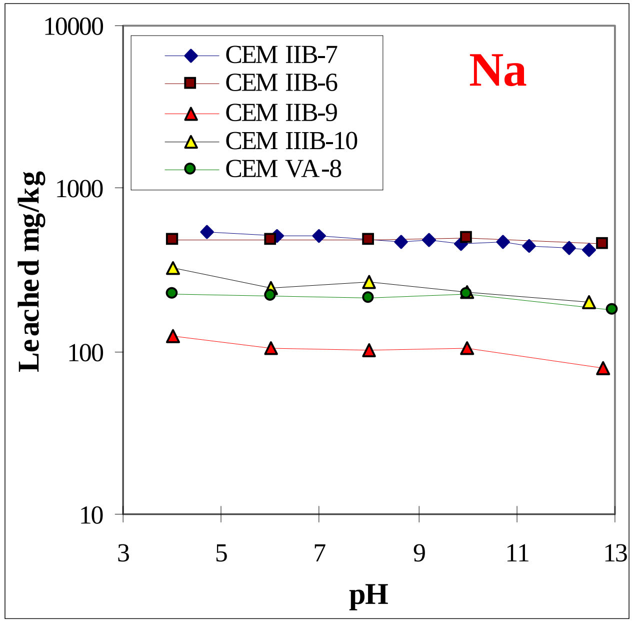

Leached mg/kg
10000
1000
100
10
1
0.1
3
5
7
9
11
13
pH
Mg
SPCEM-12
SPCEM-11

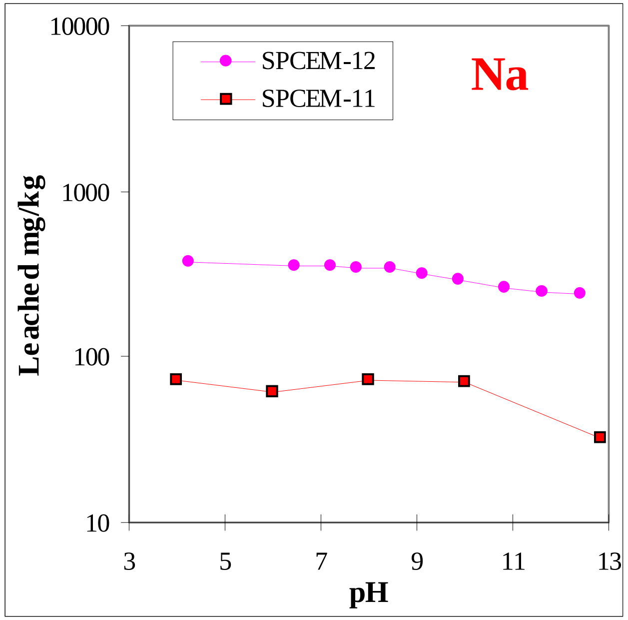

Na
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
10000
1000
100
2
4
6
8
10
12
14

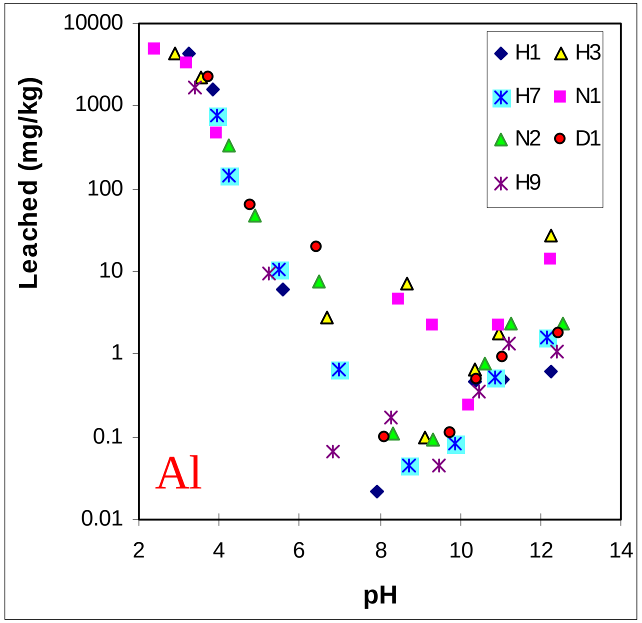

Na
Leached (mg/kg)
pH
H6
W1
W2
10000
1000
100
2
4
6
8
10
12
14

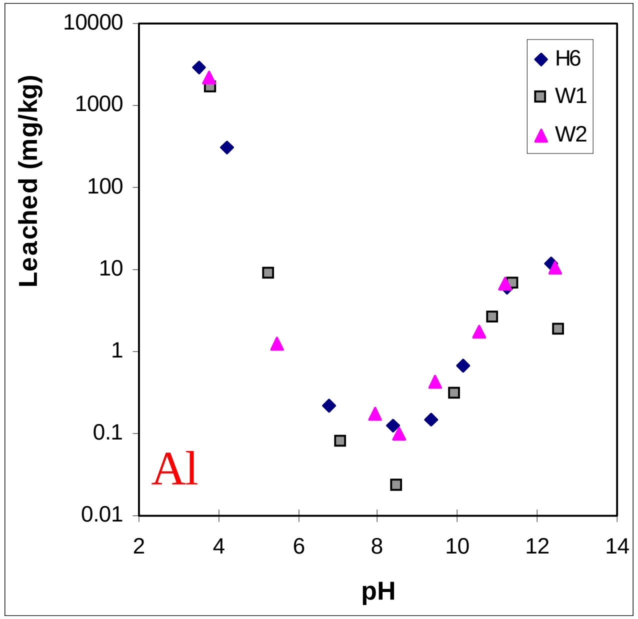

Na
Leached (mg/kg)
pH
D2
H5
10000
1000
100
2
4
6
8
10
12
14

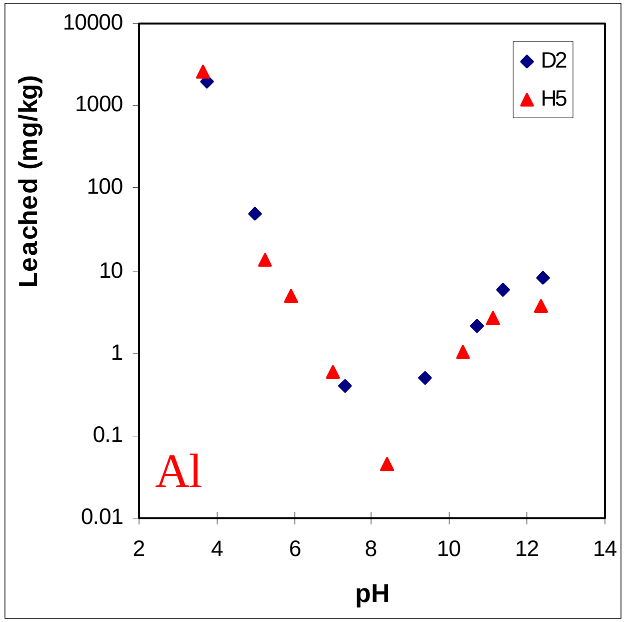

Na
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1
10000
1000
100
10
3
5
7
9
11
13

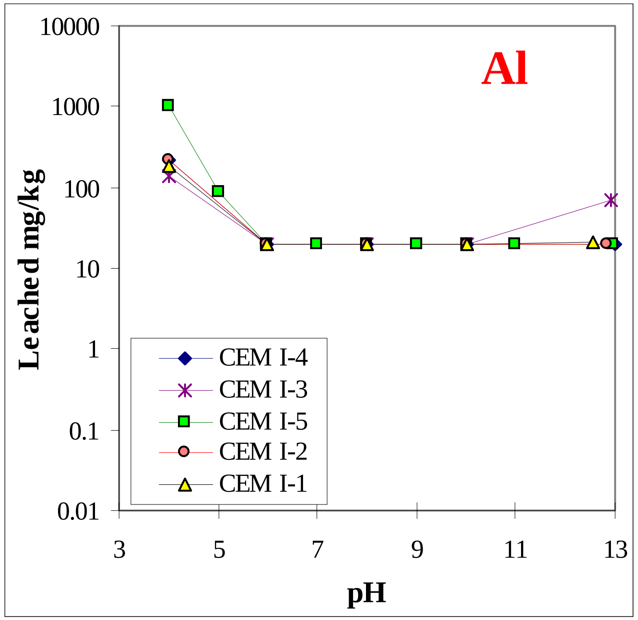

Na
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
10000
1000
100
10
3
5
7
9
11
13

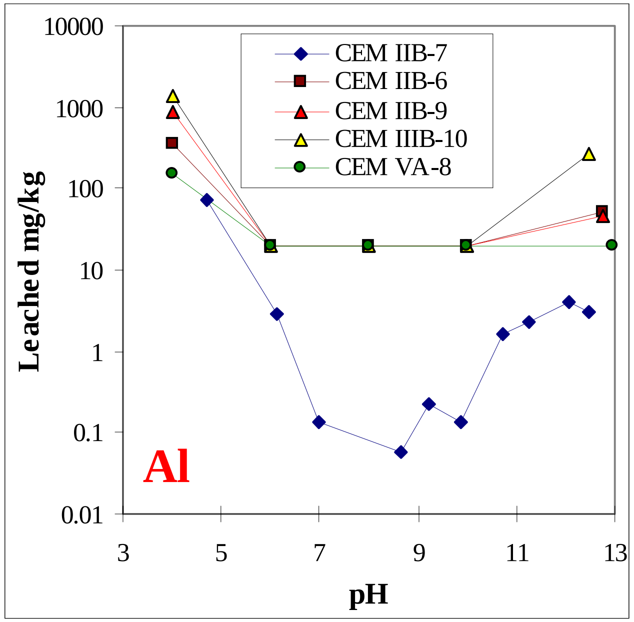

Na
Leached mg/kg
pH
SPCEM-12
SPCEM-11
10000
1000
100
10
3
5
7
9
11
13

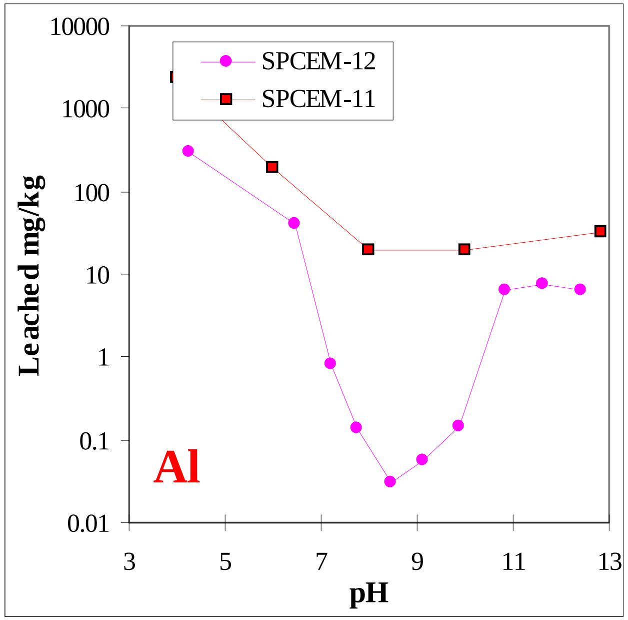

Al
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

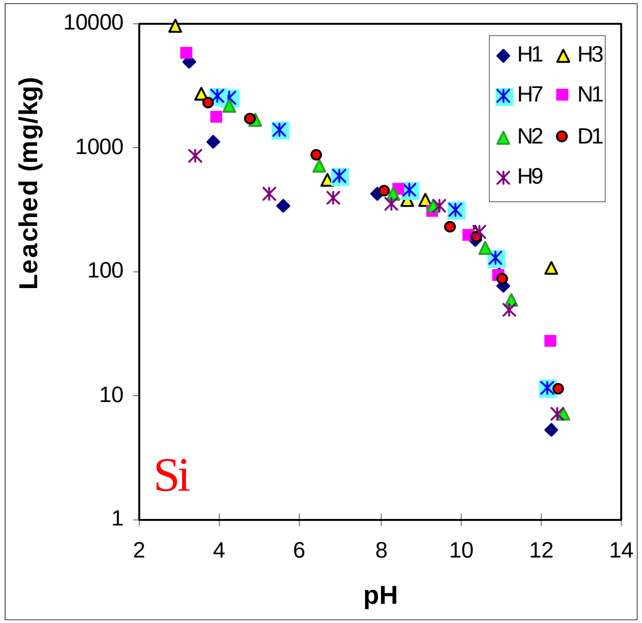

Al
Leached (mg/kg)
pH
H6
W1
W2


Al
Leached (mg/kg)
pH
D2
H5

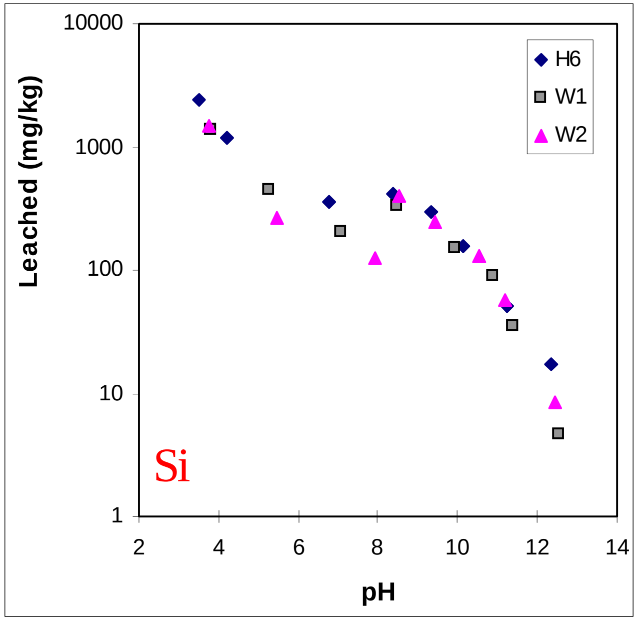

Al
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1


Al
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

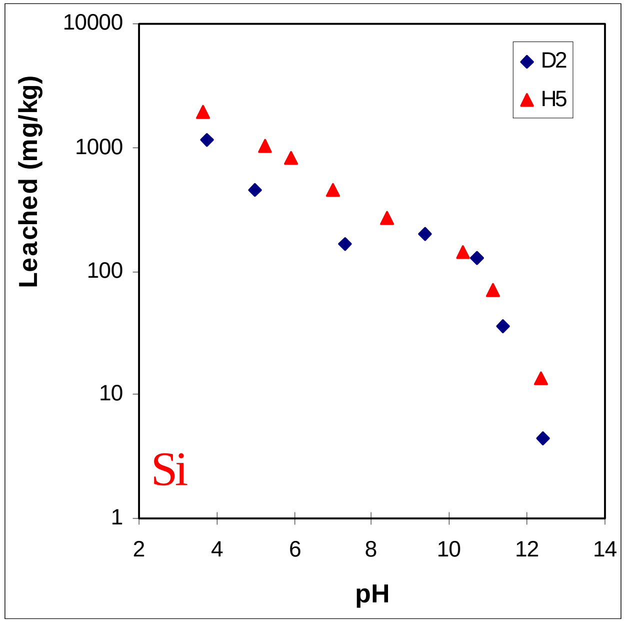

Al
Leached mg/kg
pH
SPCEM-12
SPCEM-11



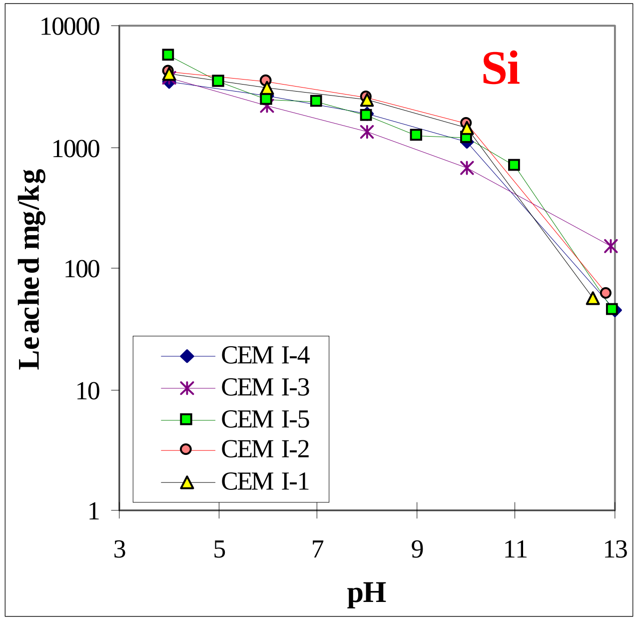
Leached (mg/kg)
pH
Si
H1
H3
H7
N1
N2
D1
H9



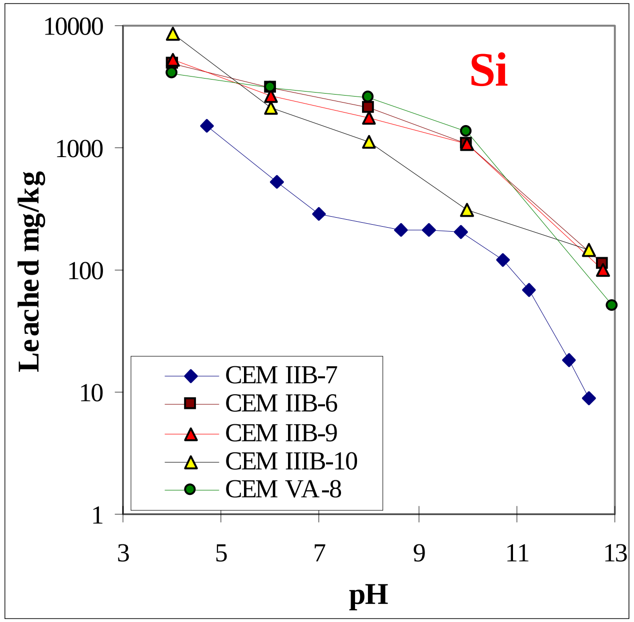
Leached (mg/kg)
pH
Si
H6
W1
W2



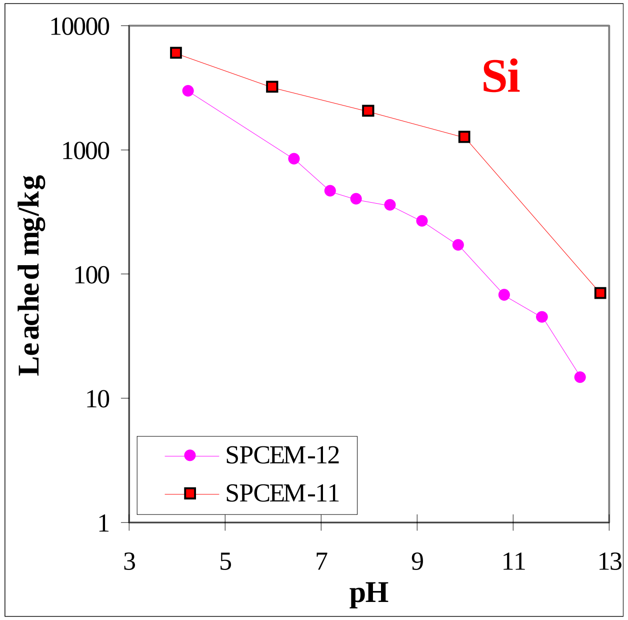
Leached (mg/kg)
pH
Si
D2
H5



Leached mg/kg
pH
Si
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

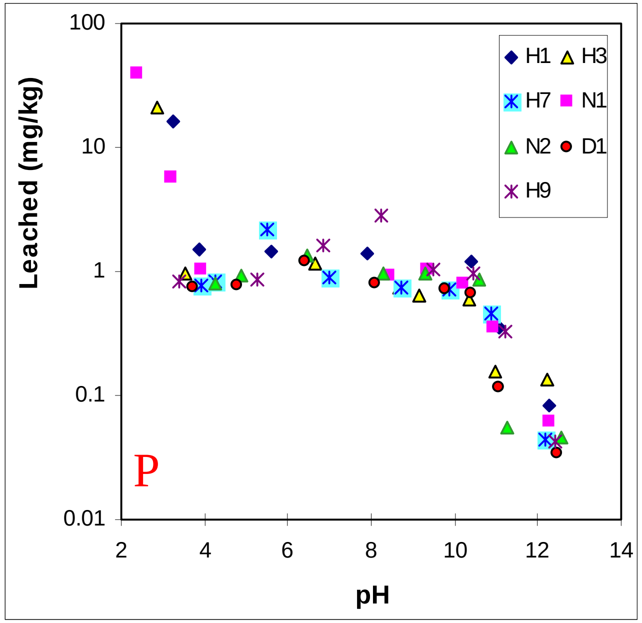


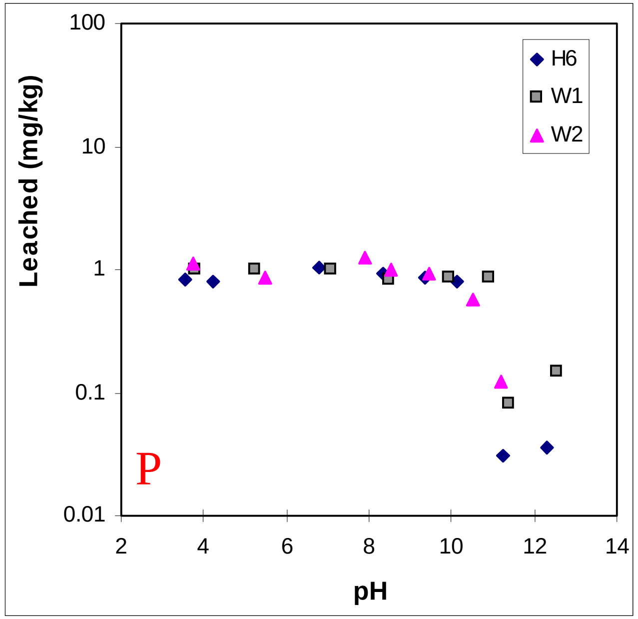
Leached mg/kg
pH
Si
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

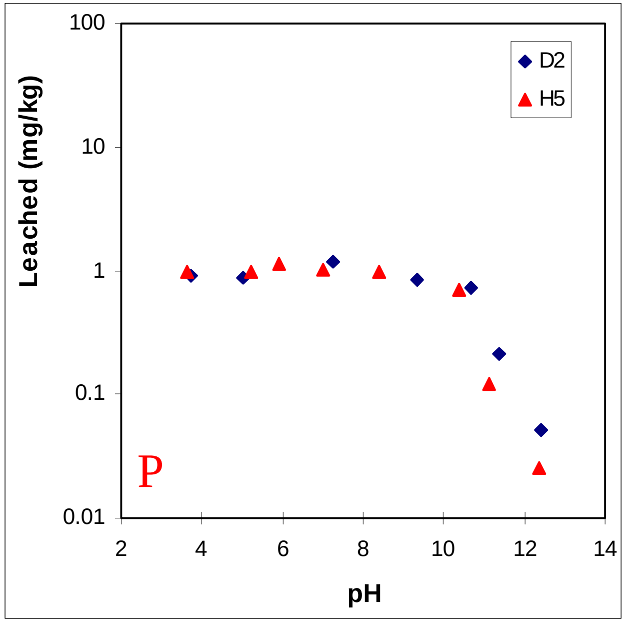


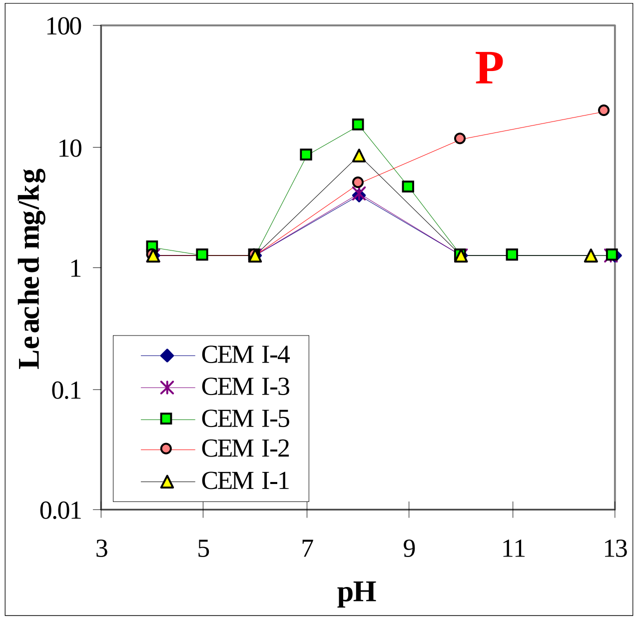
Leached mg/kg
pH
Si
SPCEM-12
SPCEM-11

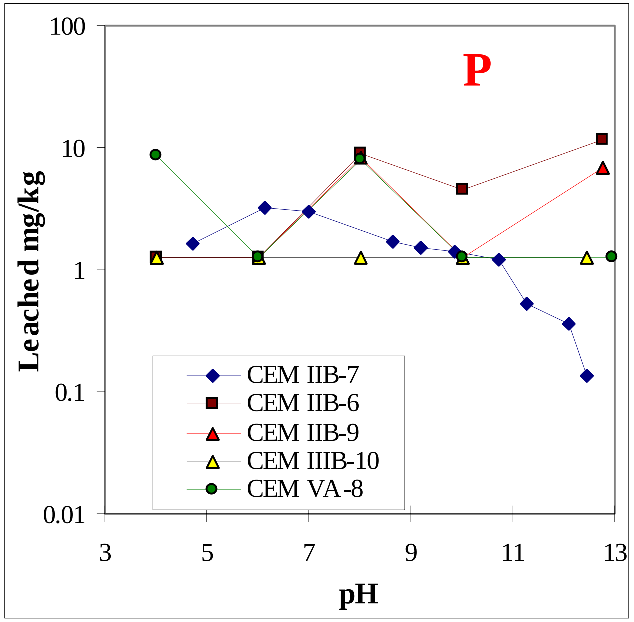
ANNEX 8 GRAPHICAL PH DEPENDENCE TEST DATA

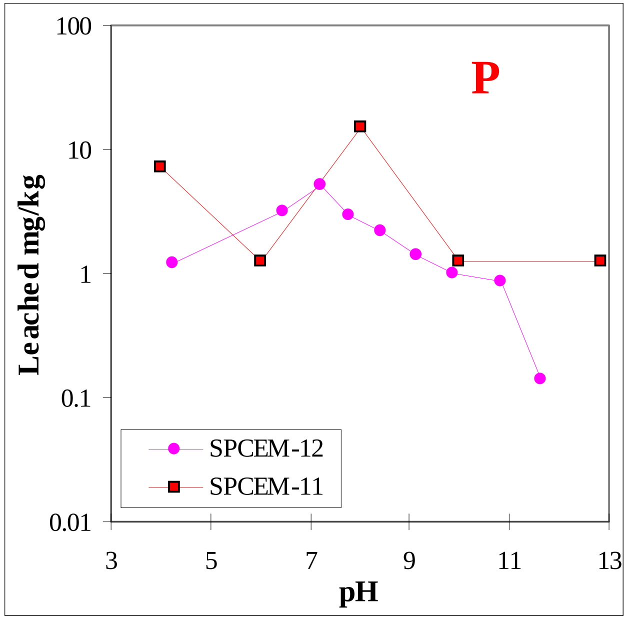


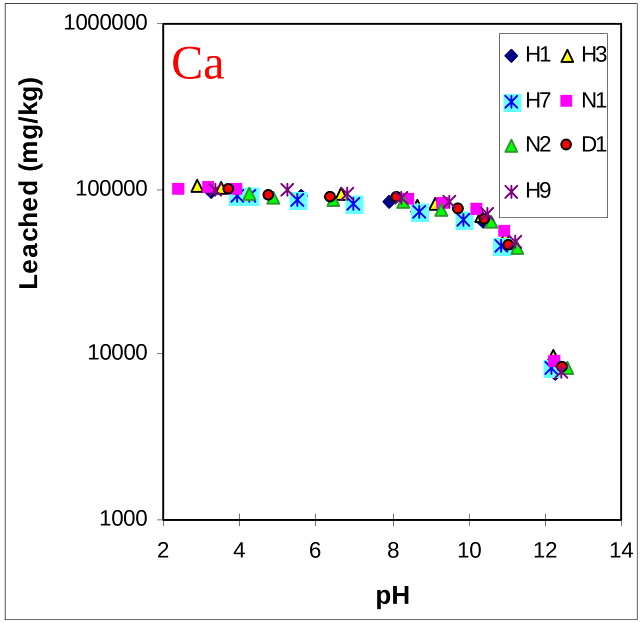


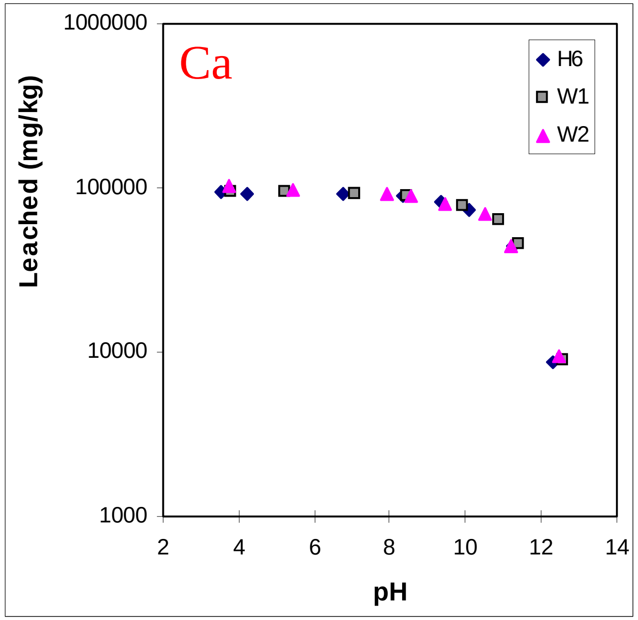


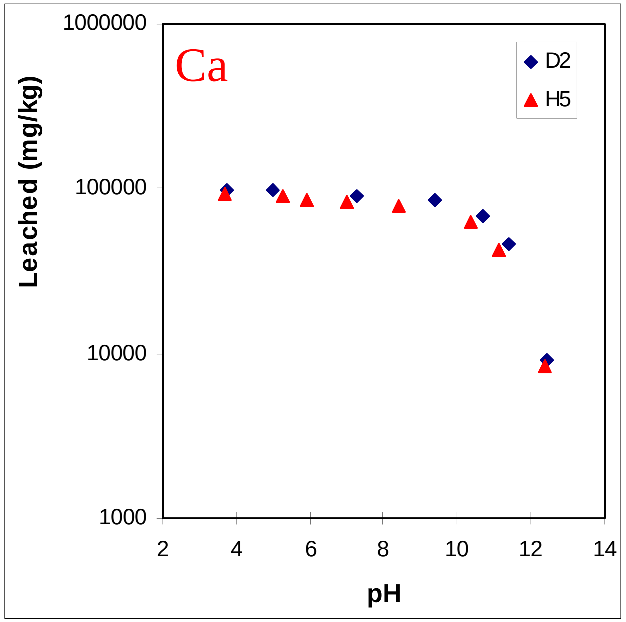


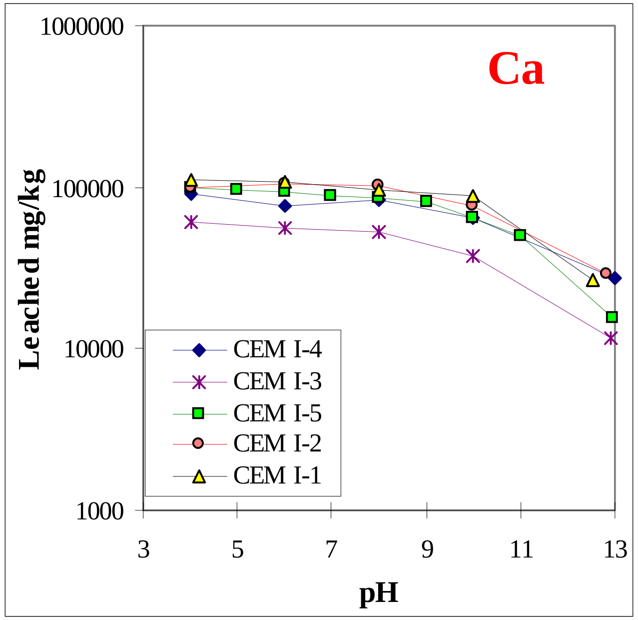


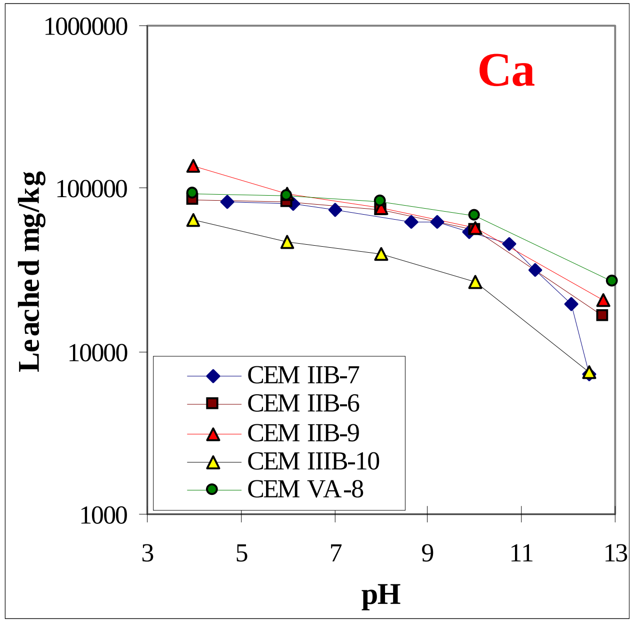


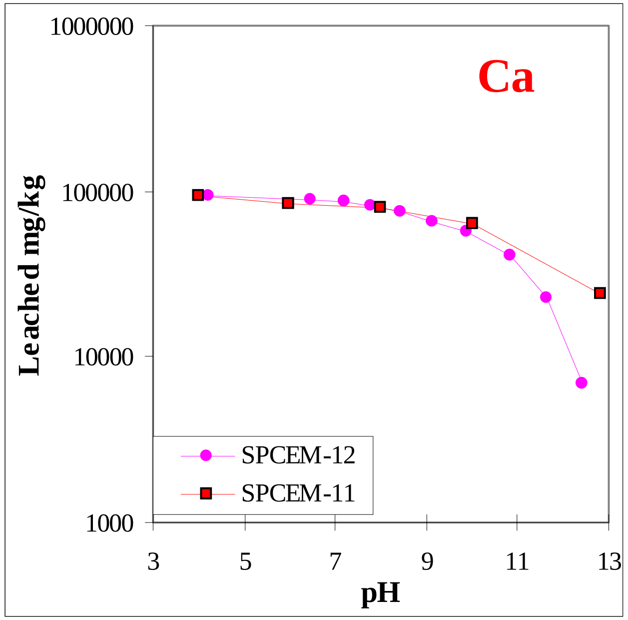

Ca
Leached (mg/kg)
1000000
100000
10000
1000
2 4 6 8 10 12 14
pH
H1
H3
H7
N1
N2
D1
H9

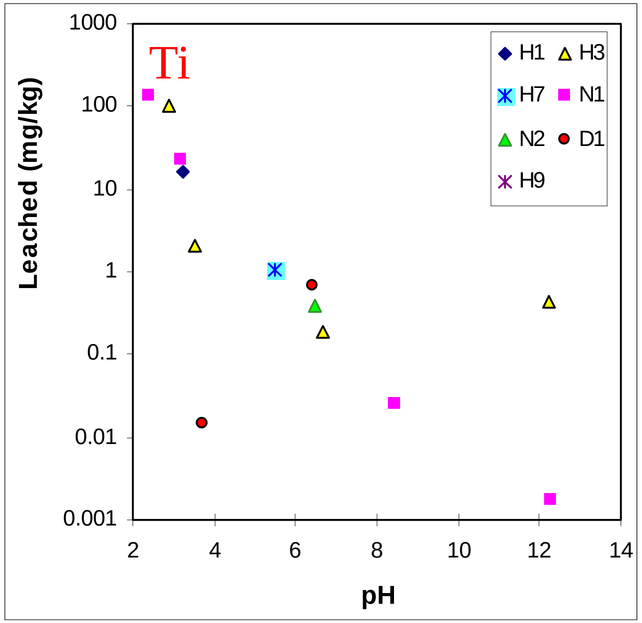

Ca
Leached (mg/kg)
1000000
100000
10000
1000
2 4 6 8 10 12 14
pH
H6
W1
W2

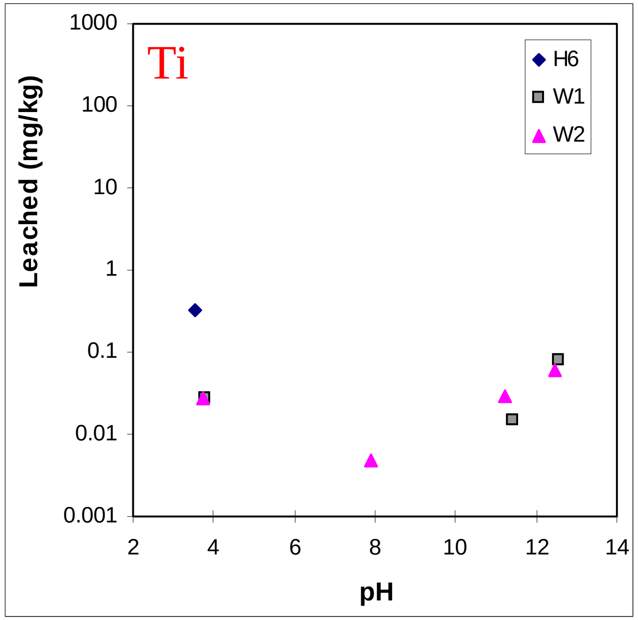

Ca
Leached (mg/kg)
1000000
100000
10000
1000
2 4 6 8 10 12 14
pH
D2
H5

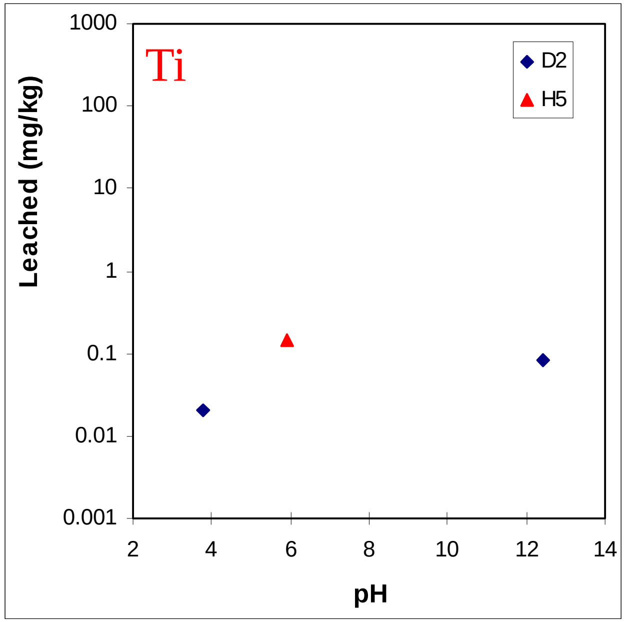

Ca
Leached mg/kg
1000000
100000
10000
1000
3 5 7 9 11 13
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

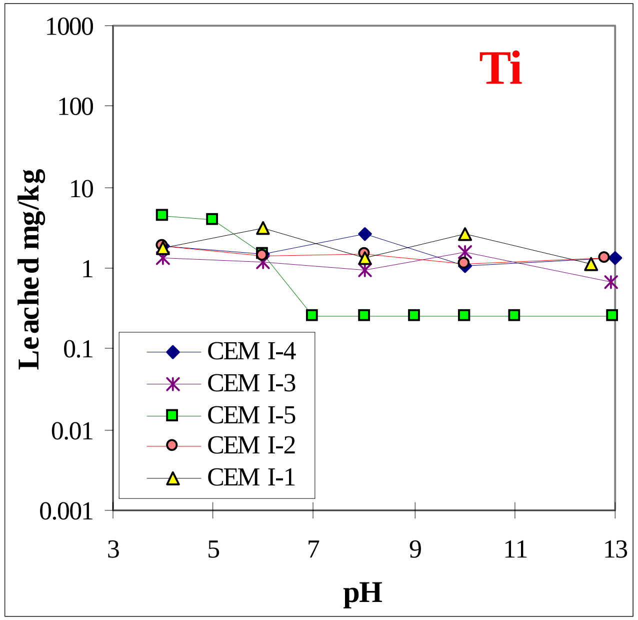

Ca
Leached mg/kg
1000000
100000
10000
1000
3 5 7 9 11 13
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

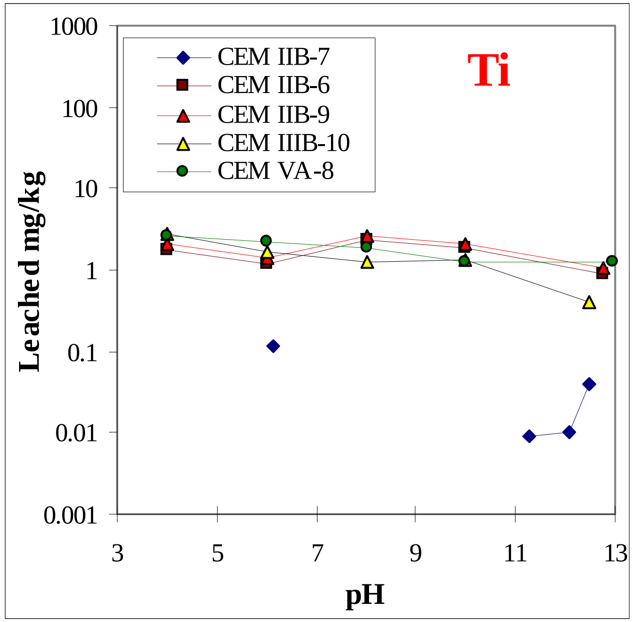

Ca
Leached mg/kg
1000000
100000
10000
1000
3 5 7 9 11 13
pH
SPCEM-12
SPCEM-11

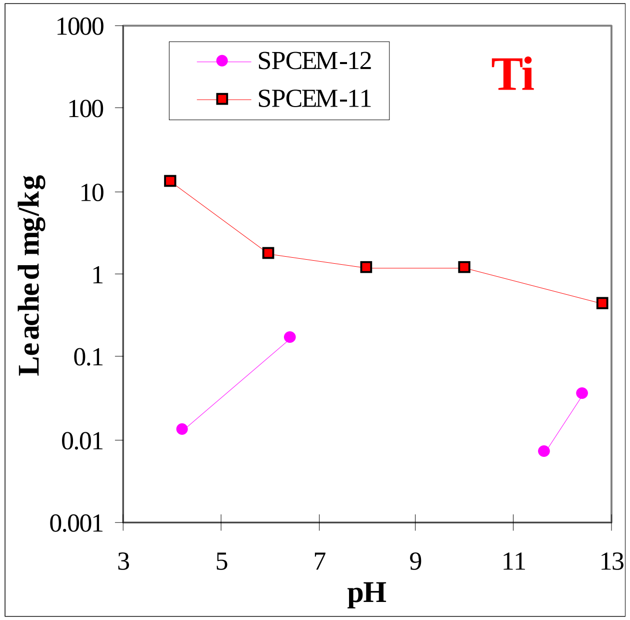

Ti
H1
H3
H7
N1
N2
D1
H9
Leached (mg/kg)
pH
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14

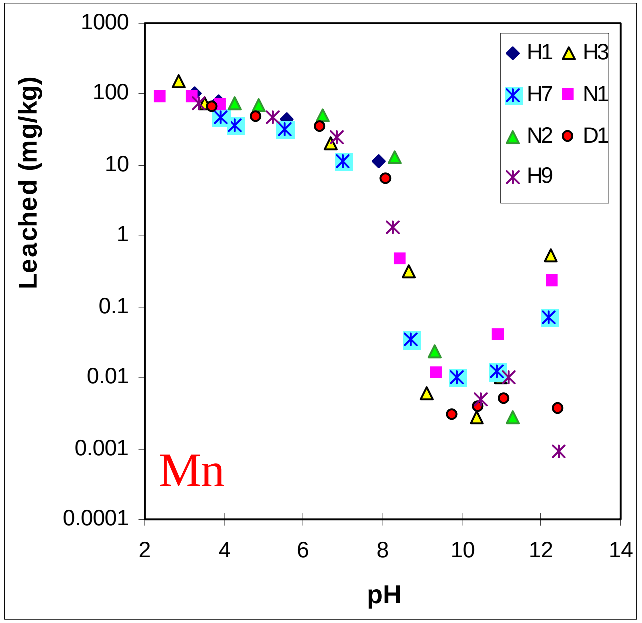

Ti
H6
W1
W2
Leached (mg/kg)
pH
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14

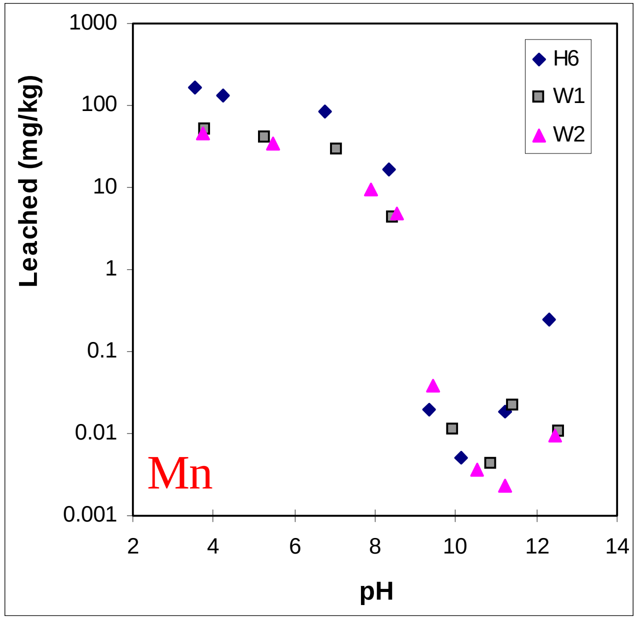

Ti
D2
H5
Leached (mg/kg)
pH
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14

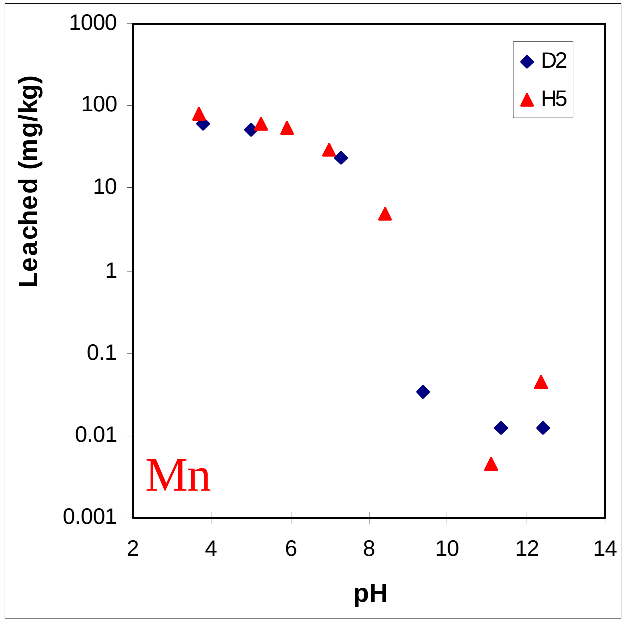

Ti
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1
Leached mg/kg
pH
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

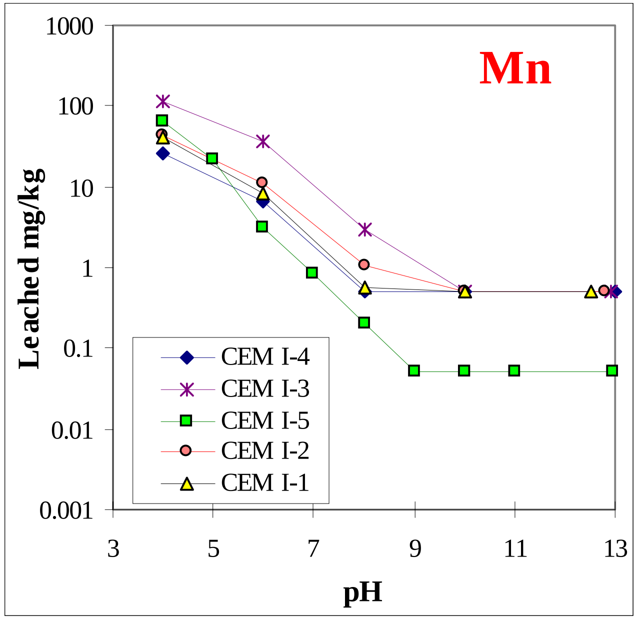

Ti
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
Leached mg/kg
pH
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

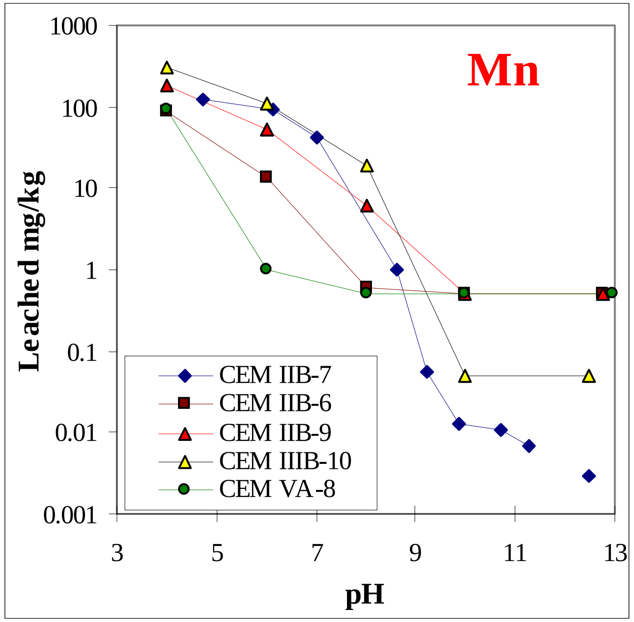

Ti
SPCEM-12
SPCEM-11
Leached mg/kg
pH
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13

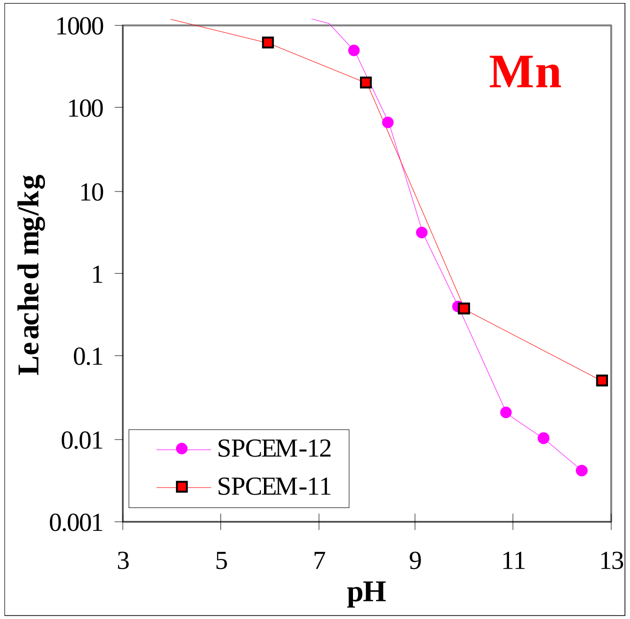

Mn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
0.0001
pH
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9

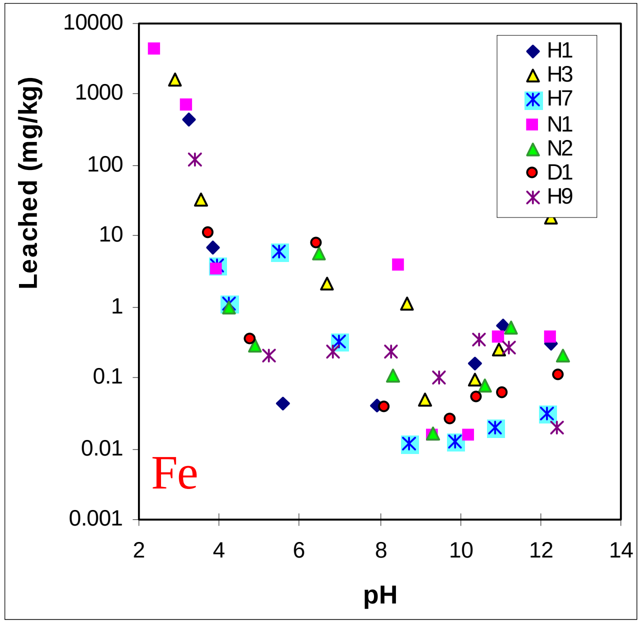

Mn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
pH
2
4
6
8
10
12
14
H6
W1
W2

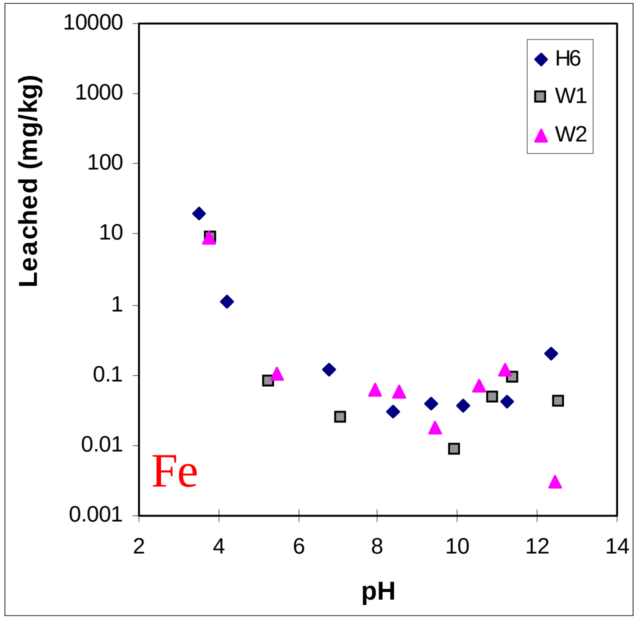

Mn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
pH
2
4
6
8
10
12
14
D2
H5

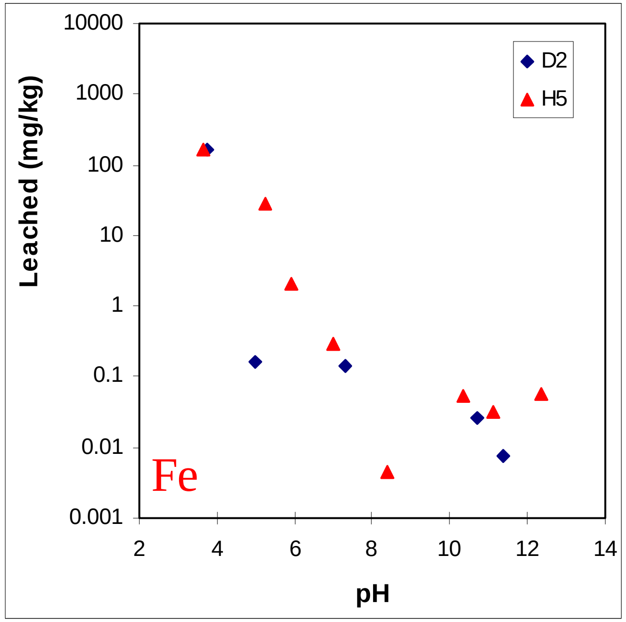

Mn
Leached mg/kg
1000
100
10
1
0.1
0.01
0.001
pH
3
5
7
9
11
13
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

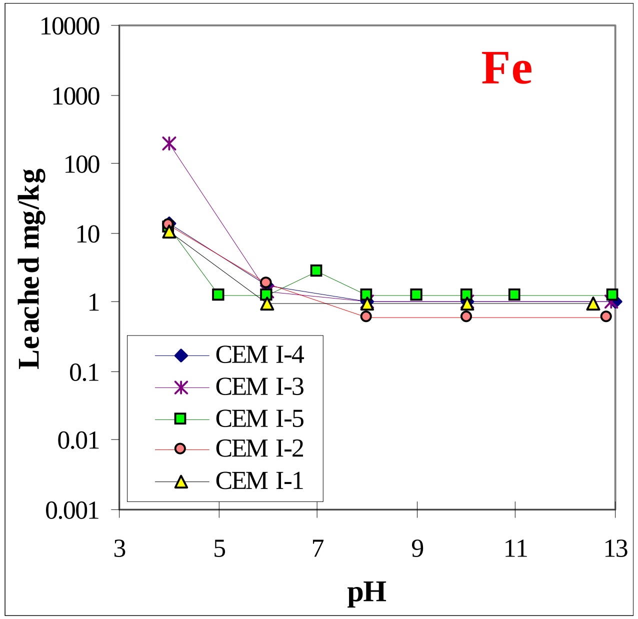

Mn
Leached mg/kg
1000
100
10
1
0.1
0.01
0.001
pH
3
5
7
9
11
13
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

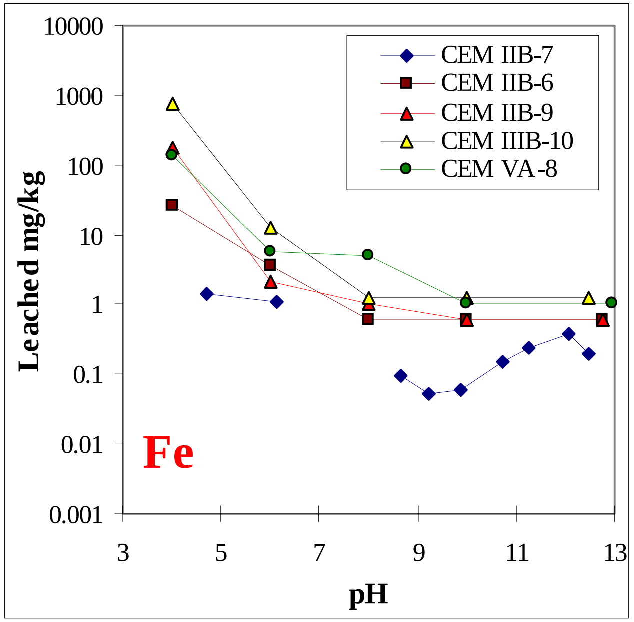

Mn
Leached mg/kg
1000
100
10
1
0.1
0.01
0.001
pH
3
5
7
9
11
13
SPCEM-12
SPCEM-11

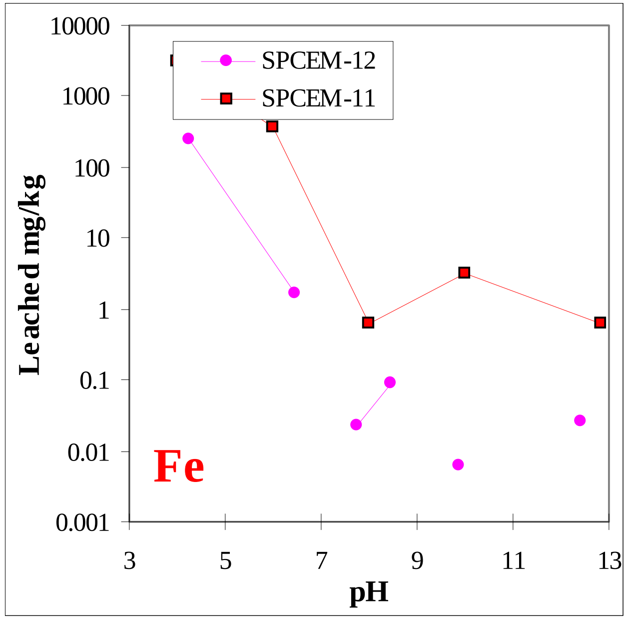

Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
Fe

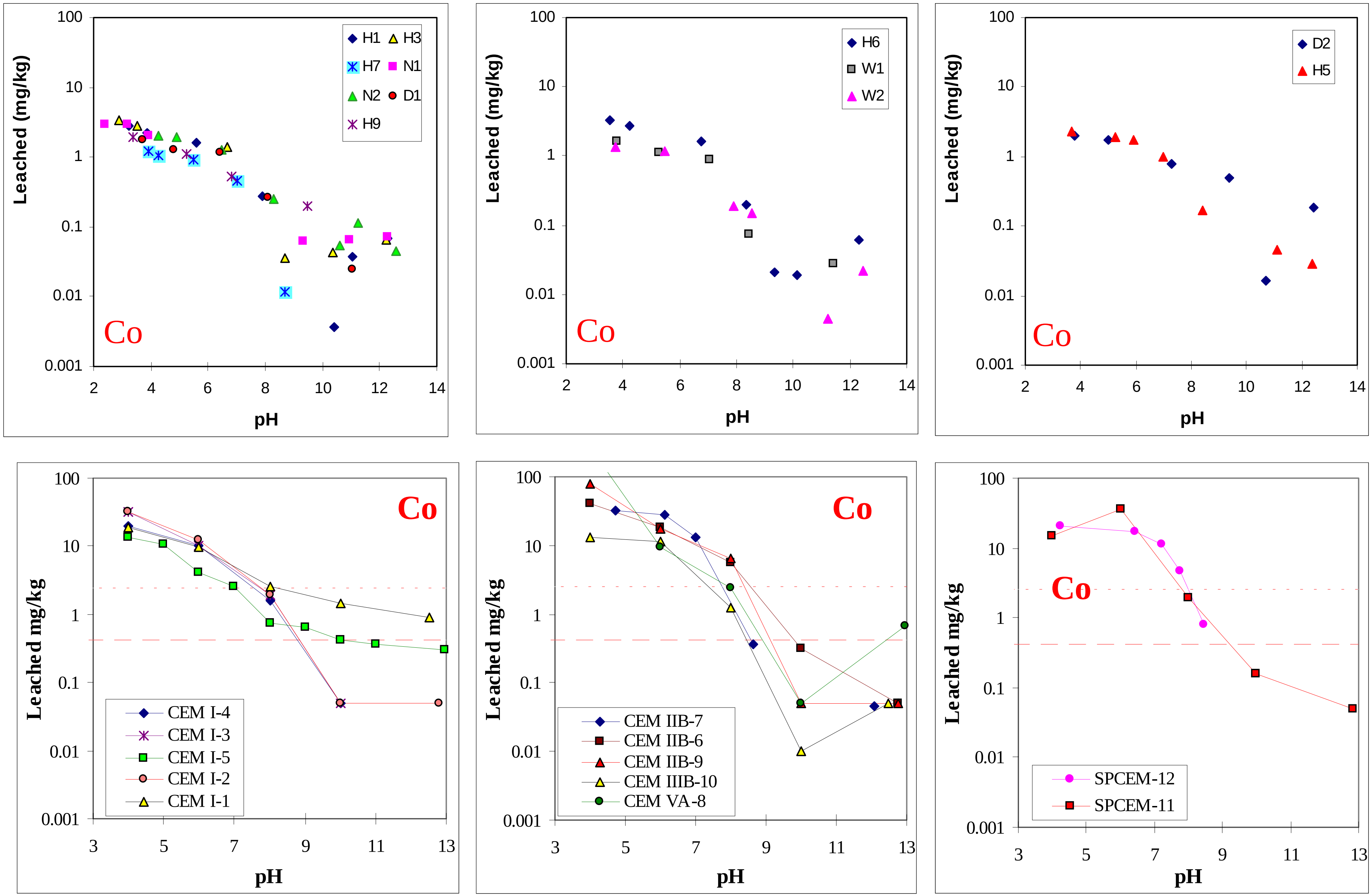

Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H6
W1
W2
Fe

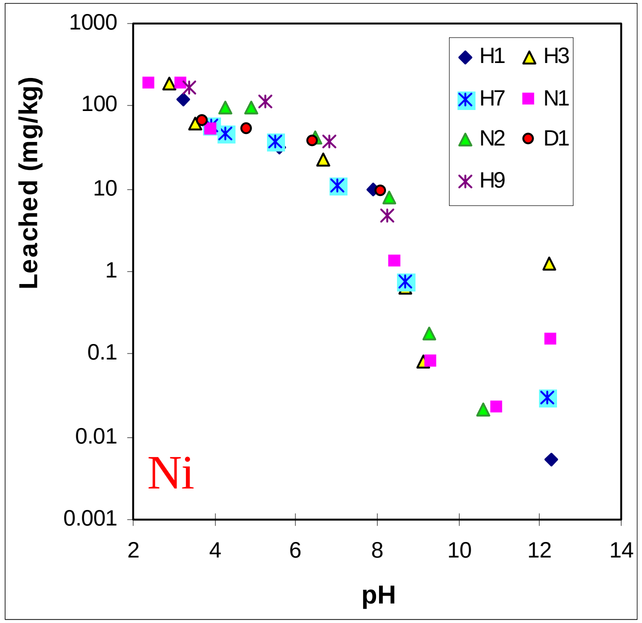

Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
Fe

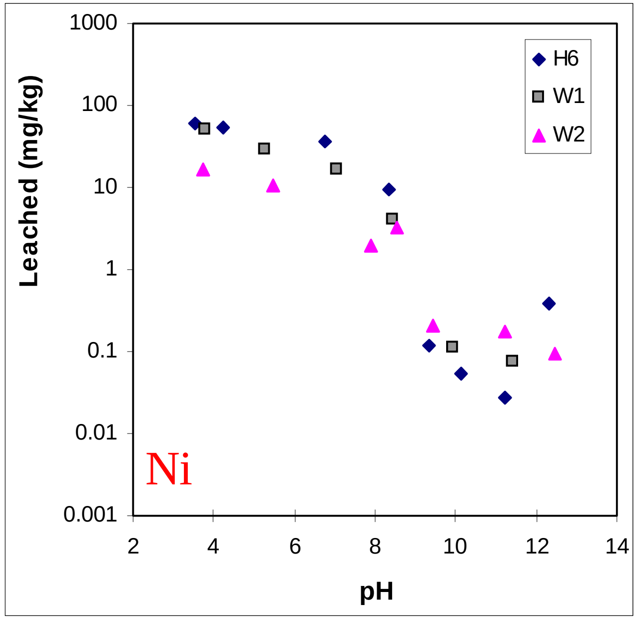

Leached mg/kg
10000
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13
pH
Fe
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

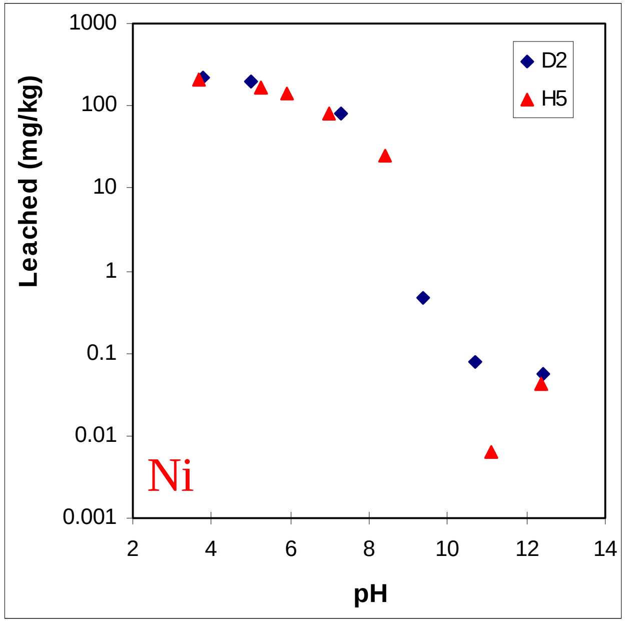

Leached mg/kg
10000
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
Fe

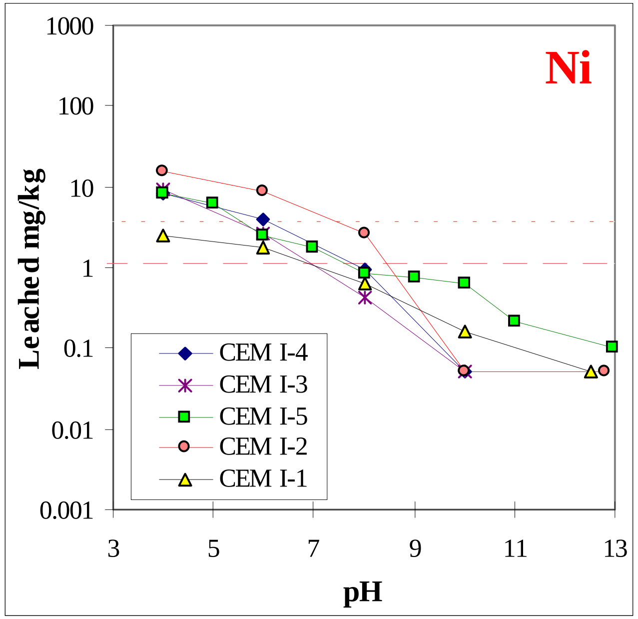

Leached mg/kg
10000
1000
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13
pH
SPCEM-12
SPCEM-11
Fe

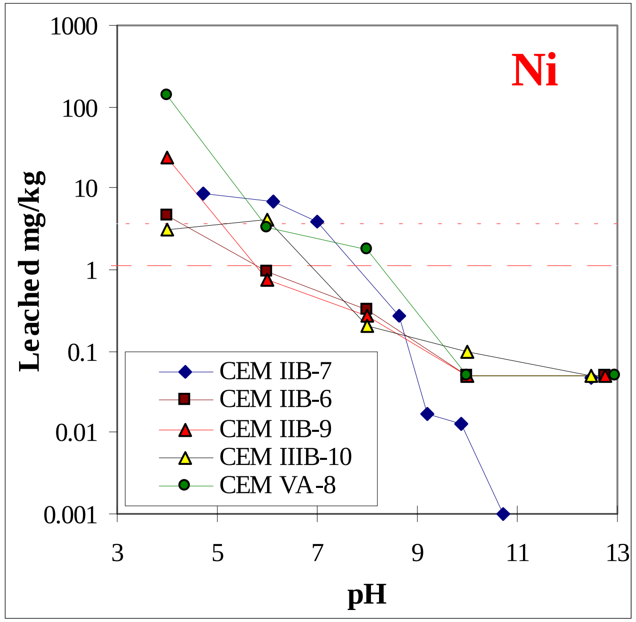

Co
Leached (mg/kg)
pH
H1 H3 H7 N1 N2 D1 H9
H6 W1 W2
D2 H5
Leached mg/kg
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8
SPCEM-12
SPCEM-11

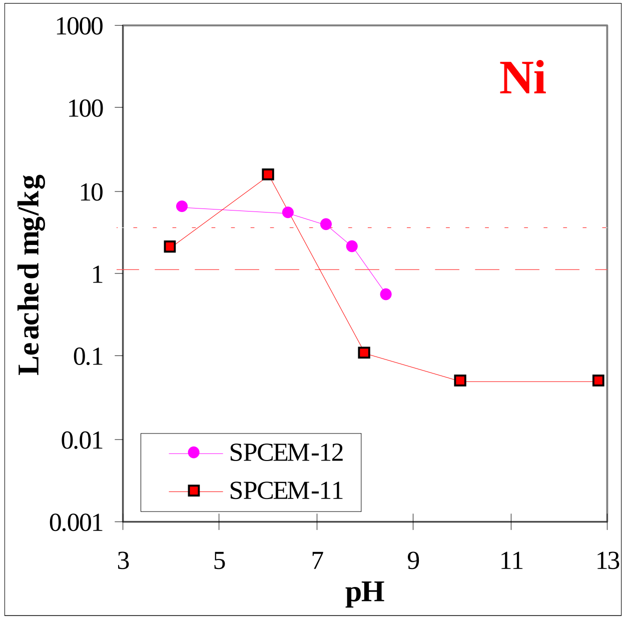

Ni
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

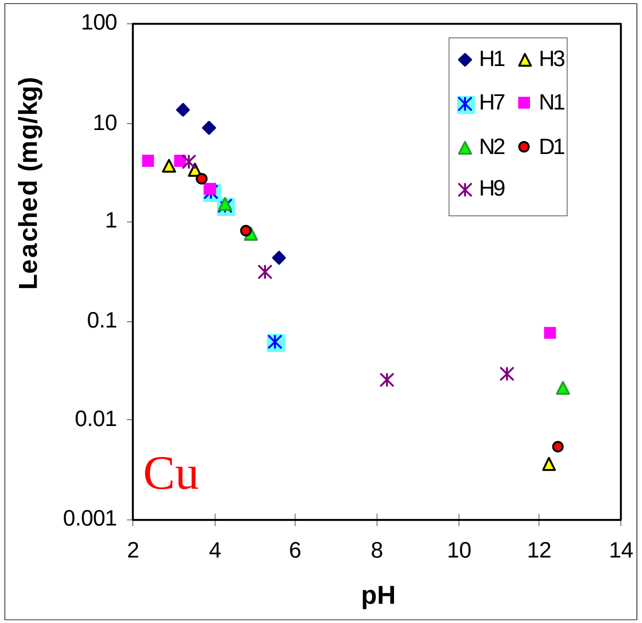

Ni
Leached (mg/kg)
pH
H6
W1
W2

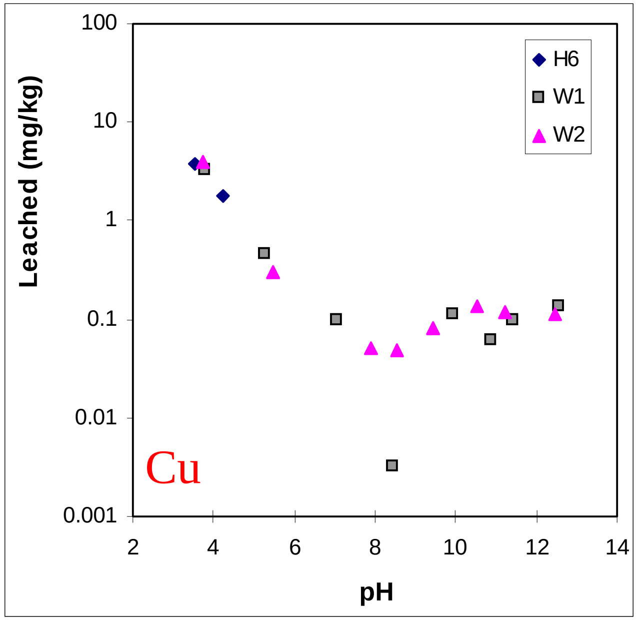

Ni
Leached (mg/kg)
pH
D2
H5

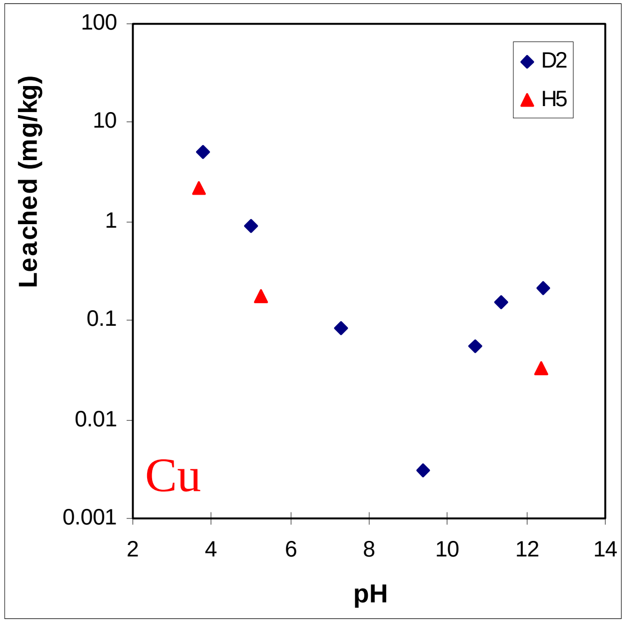

Ni
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

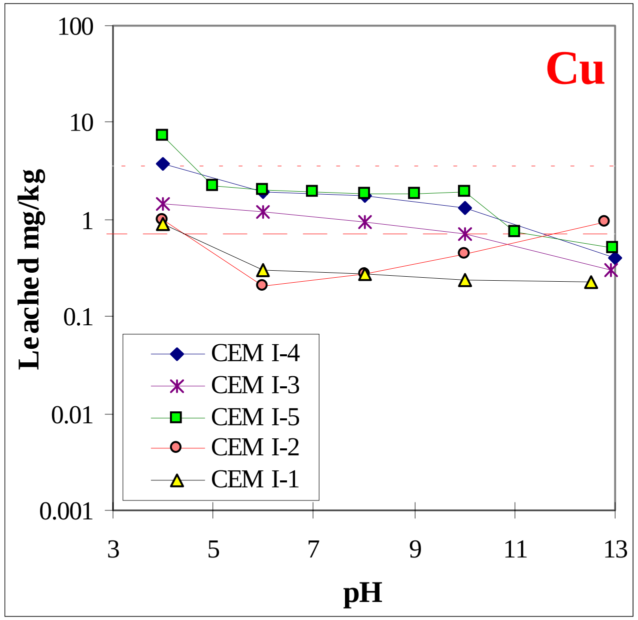

Ni
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

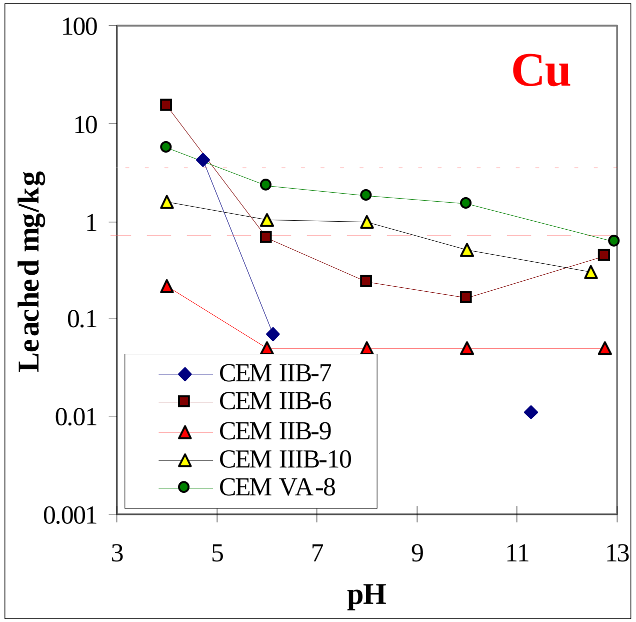

Ni
Leached mg/kg
pH
SPCEM-12
SPCEM-11

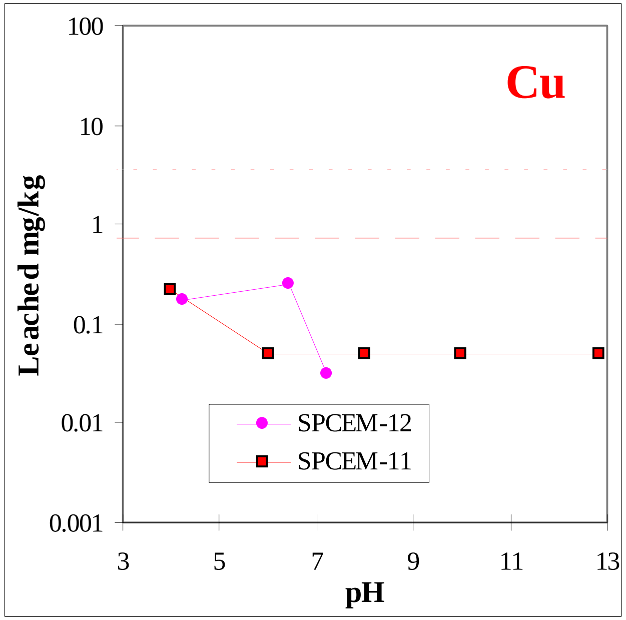

Cu
Leached (mg/kg)
pH
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9

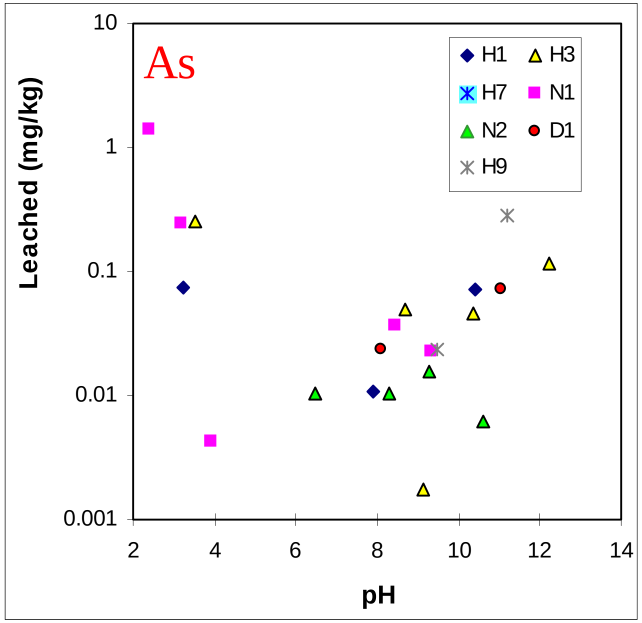

Cu
Leached (mg/kg)
pH
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H6
W1
W2

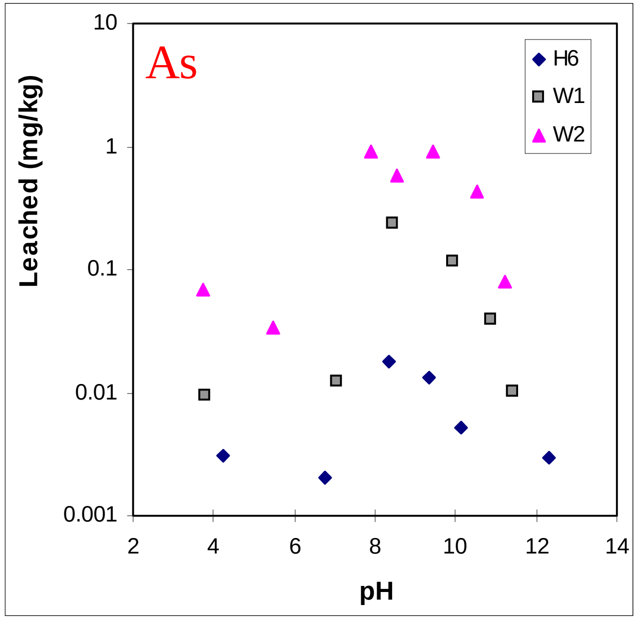

Cu
Leached (mg/kg)
pH
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
D2
H5

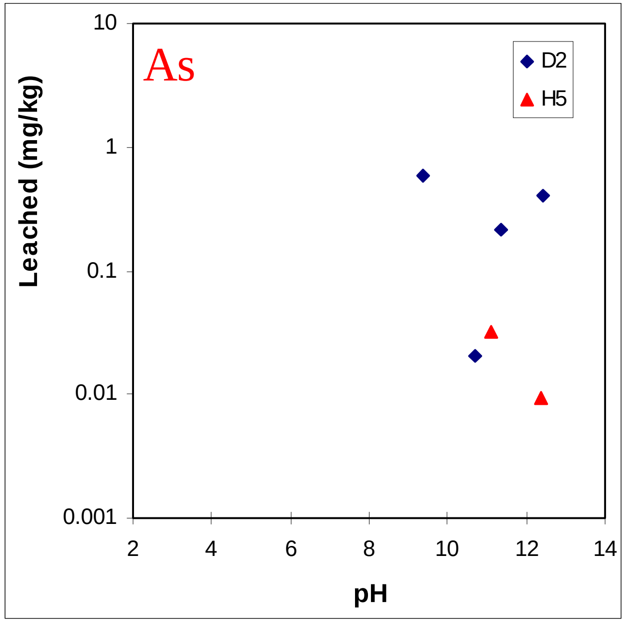

Cu
Leached mg/kg
pH
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

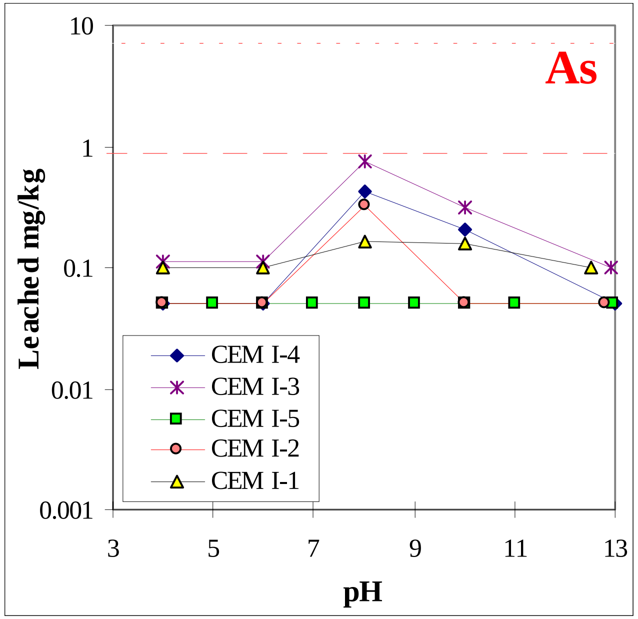

Cu
Leached mg/kg
pH
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

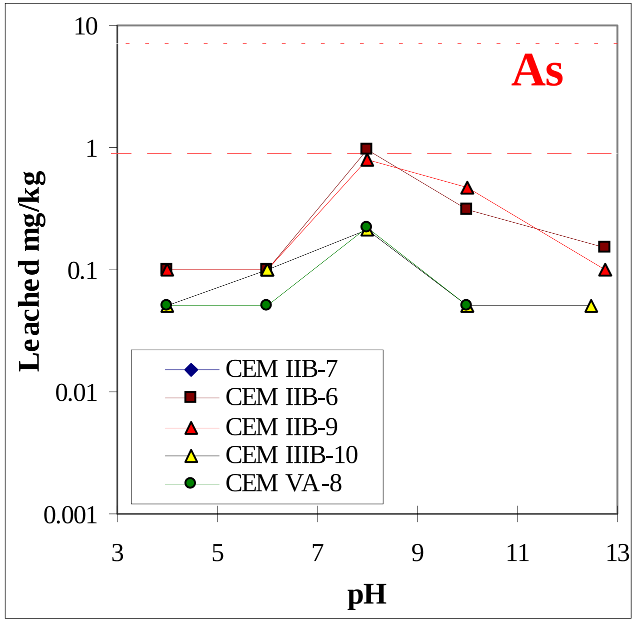

Cu
Leached mg/kg
pH
100
10
1
0.1
0.01
0.001
3
5
7
9
11
13
SPCEM-12
SPCEM-11

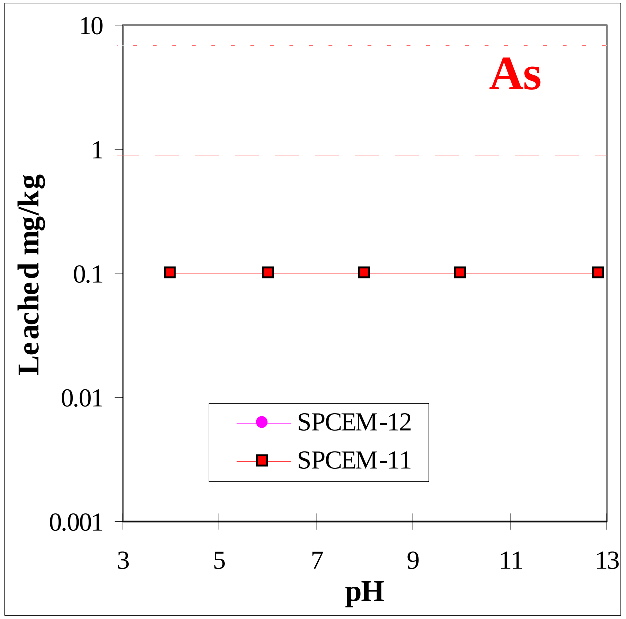

As
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

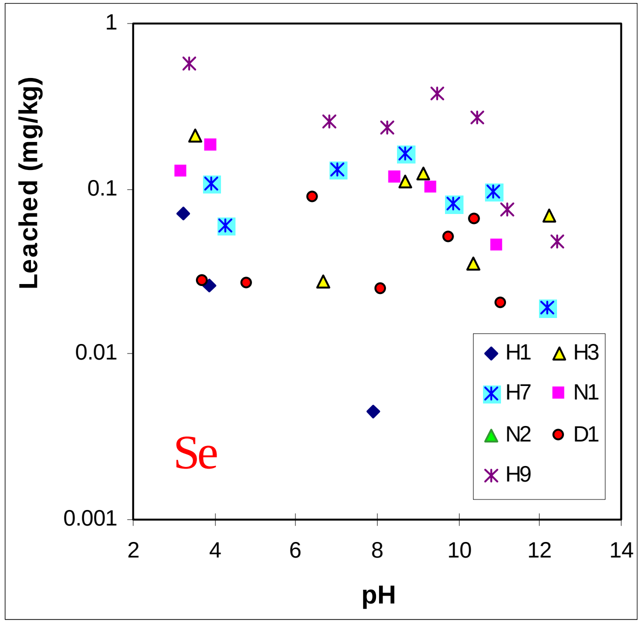

As
Leached (mg/kg)
pH
H6
W1
W2

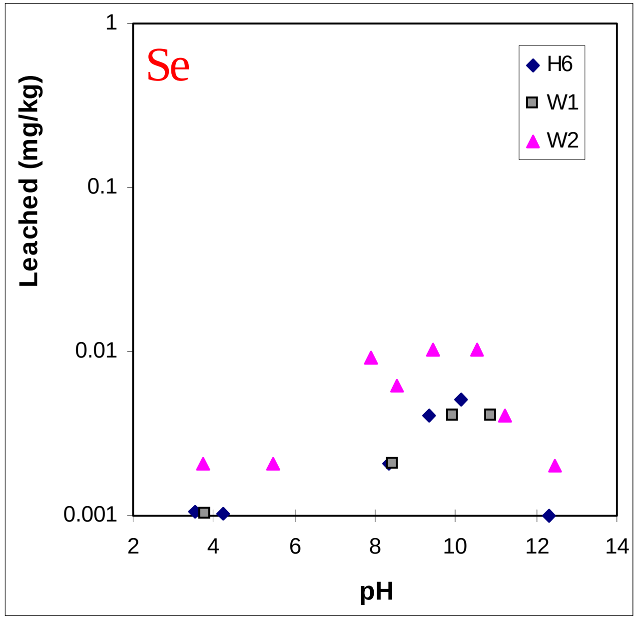

As
Leached (mg/kg)
pH
D2
H5

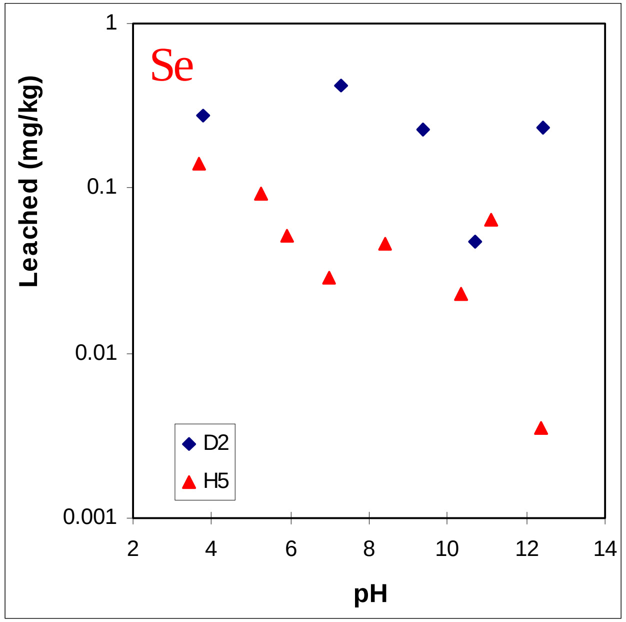

As
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

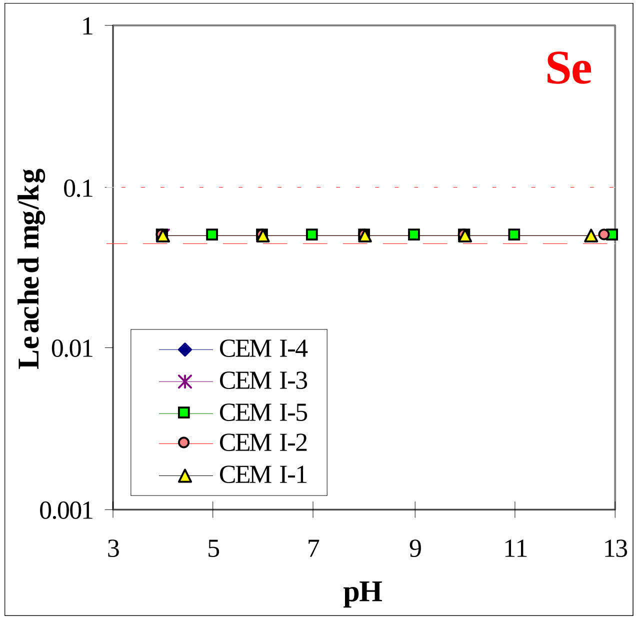

As
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

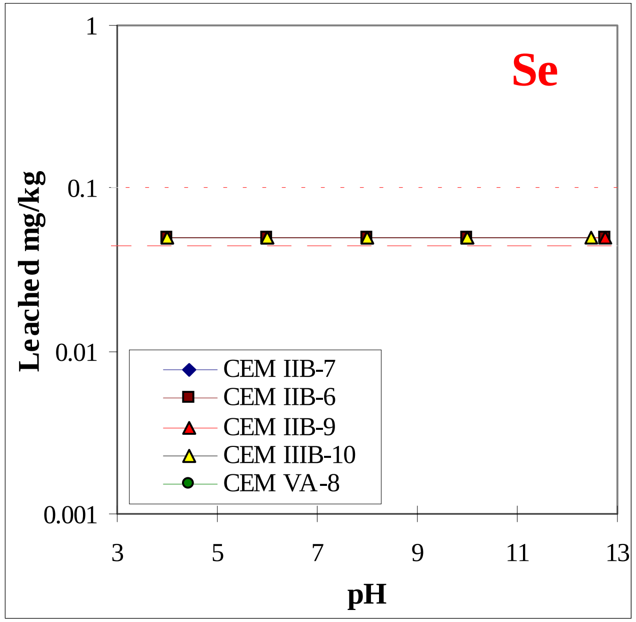

As
Leached mg/kg
pH
SPCEM-12
SPCEM-11

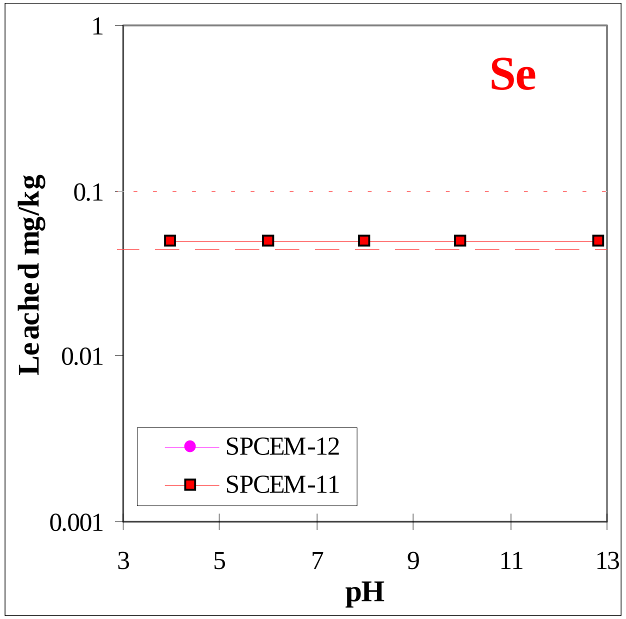

Se
Leached (mg/kg)
pH
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9

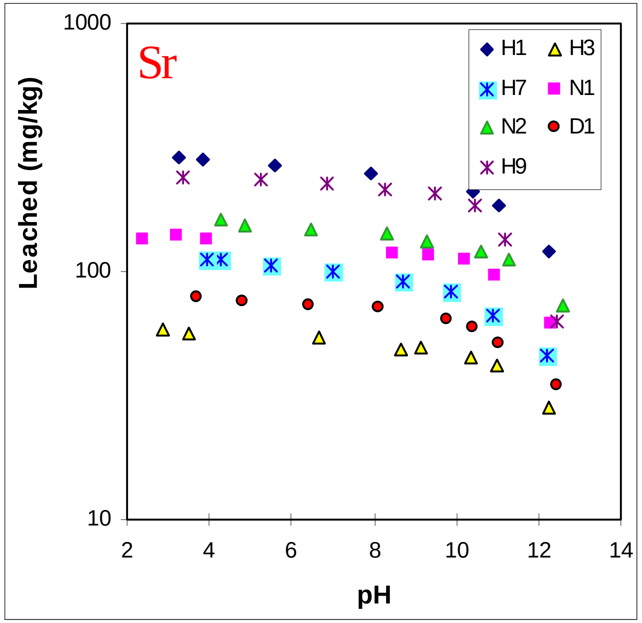

Se
Leached (mg/kg)
pH
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H6
W1
W2

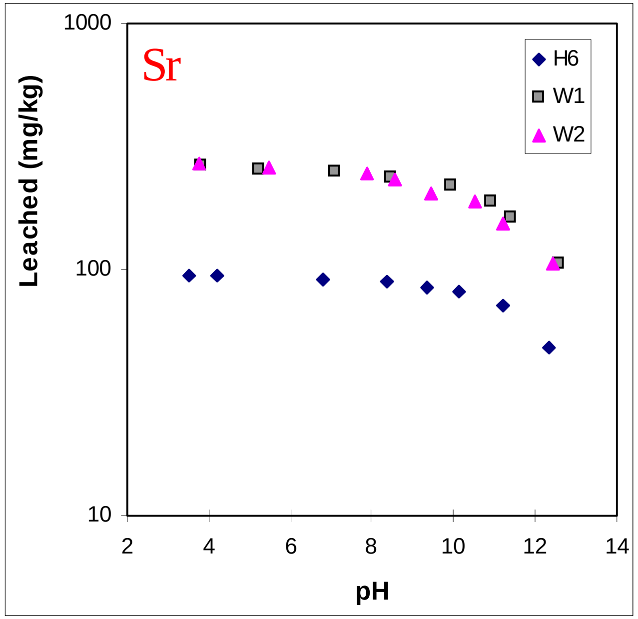

Se
Leached (mg/kg)
pH
1
0.1
0.01
0.001
2
4
6
8
10
12
14
D2
H5

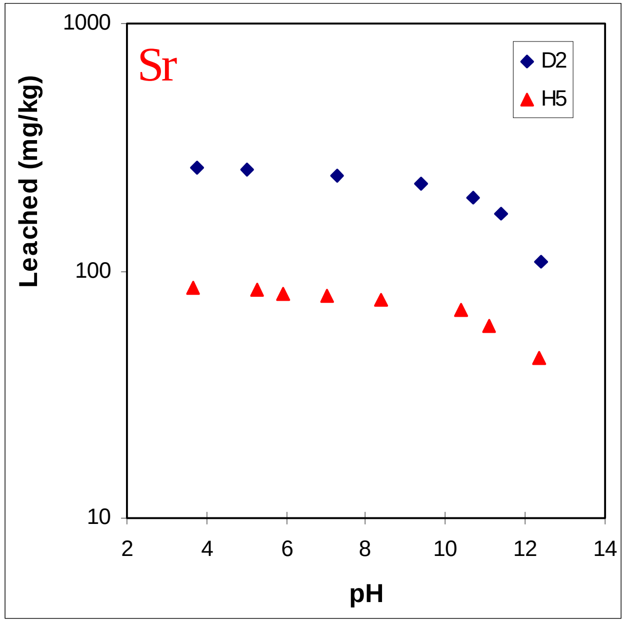

Se
Leached mg/kg
pH
1
0.1
0.01
0.001
3
5
7
9
11
13
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

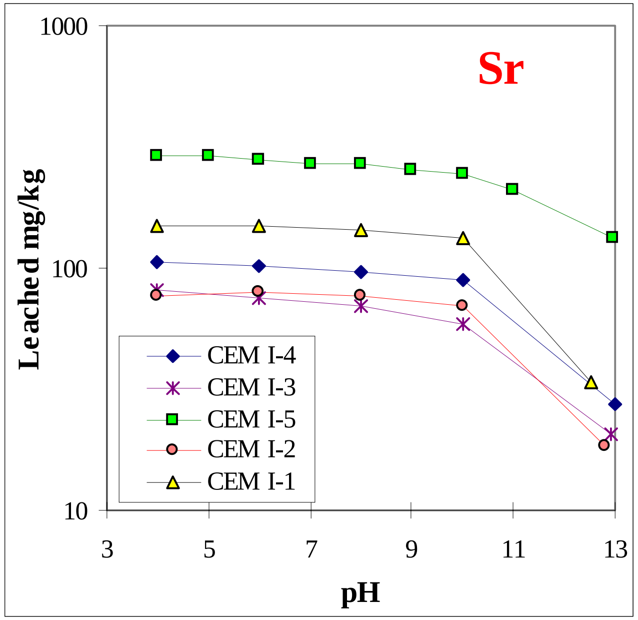

Se
Leached mg/kg
pH
1
0.1
0.01
0.001
3
5
7
9
11
13
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

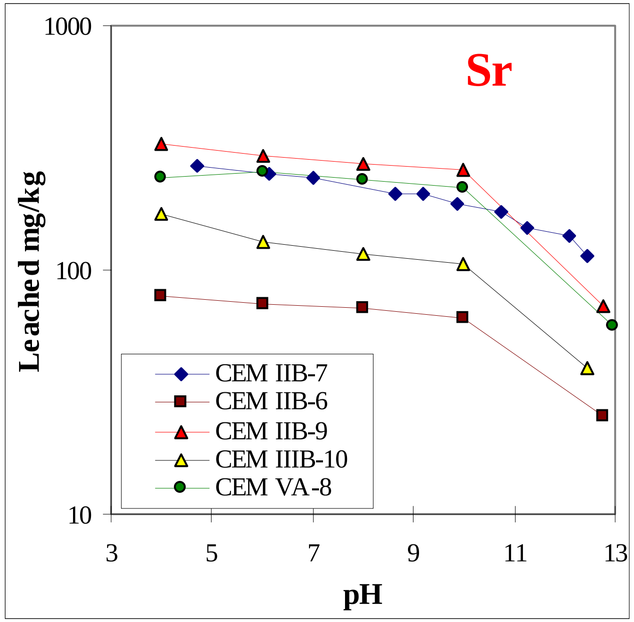

Se
Leached mg/kg
pH
1
0.1
0.01
0.001
3
5
7
9
11
13
SPCEM-12
SPCEM-11

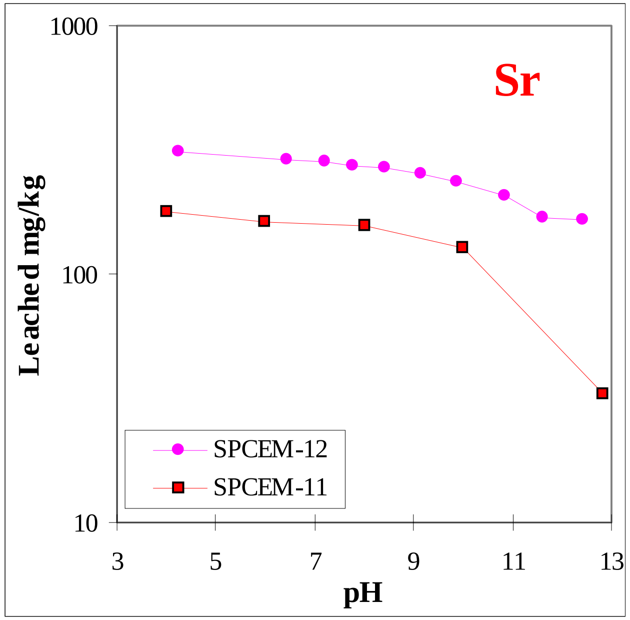

Sr
Leached (mg/kg)
1000
100
10
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9

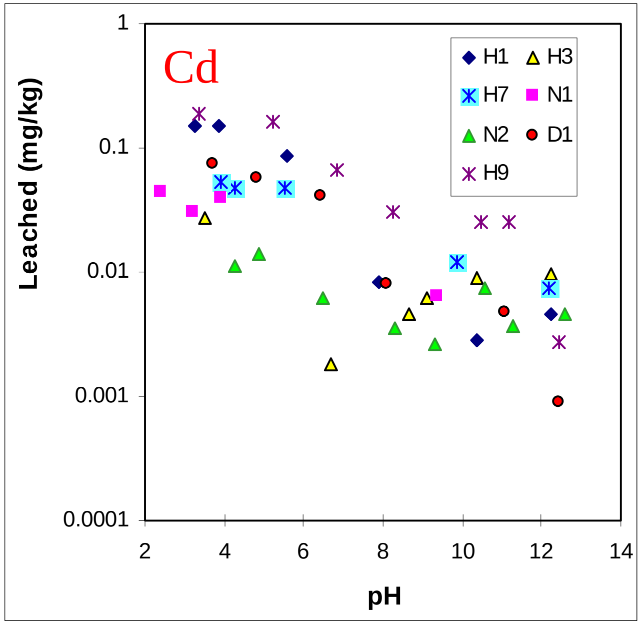

Sr
Leached (mg/kg)
1000
100
10
2
4
6
8
10
12
14
pH
H6
W1
W2

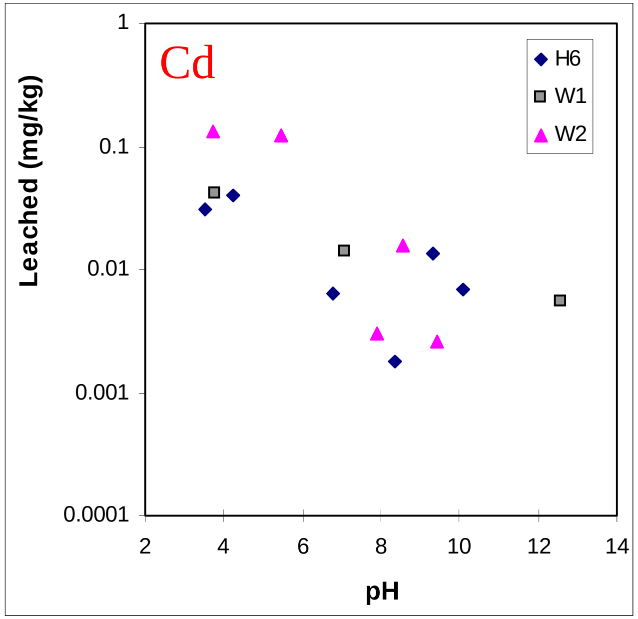

Sr
Leached (mg/kg)
1000
100
10
2
4
6
8
10
12
14
pH
D2
H5

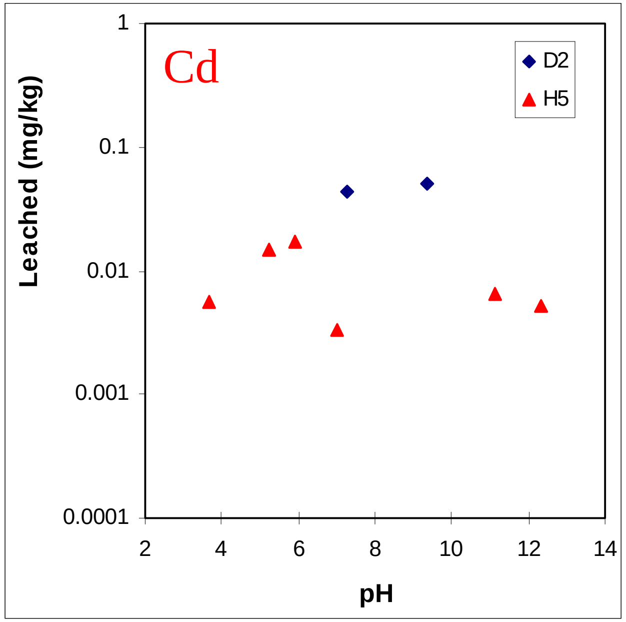

Sr
Leached mg/kg
1000
100
10
3
5
7
9
11
13
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

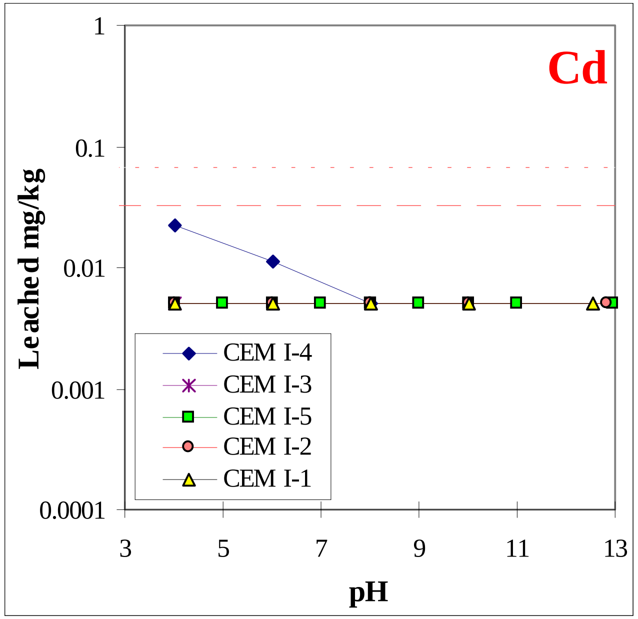

Sr
Leached mg/kg
1000
100
10
3
5
7
9
11
13
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

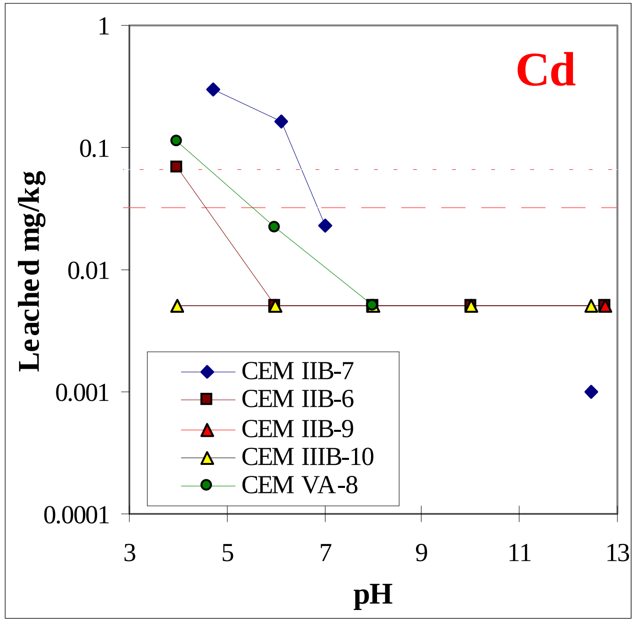

Sr
Leached mg/kg
1000
100
10
3
5
7
9
11
13
pH
SPCEM-12
SPCEM-11

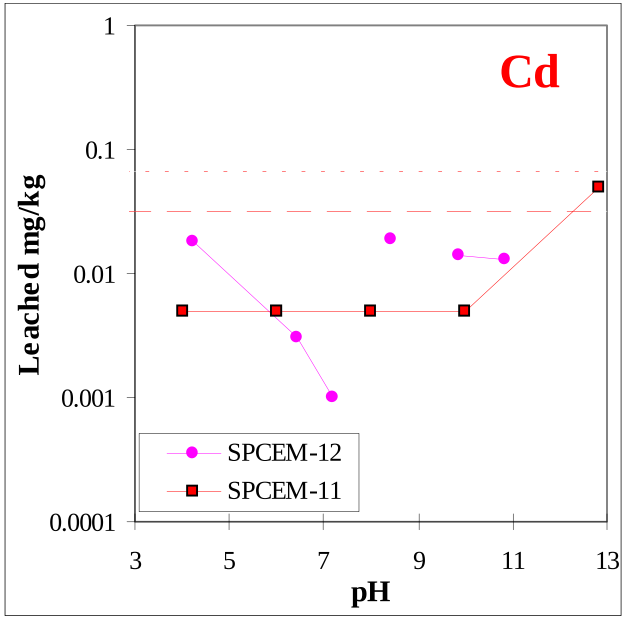

Cd
Leached (mg/kg)
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9

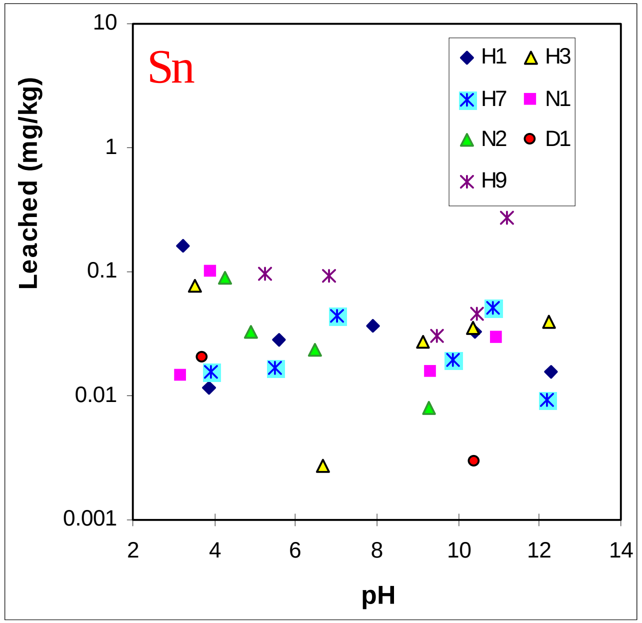

Cd
Leached (mg/kg)
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H6
W1
W2

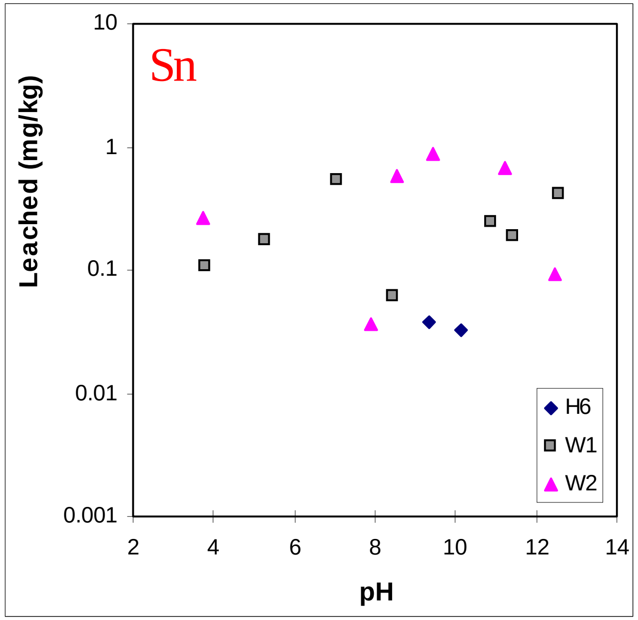

Cd
Leached (mg/kg)
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
D2
H5

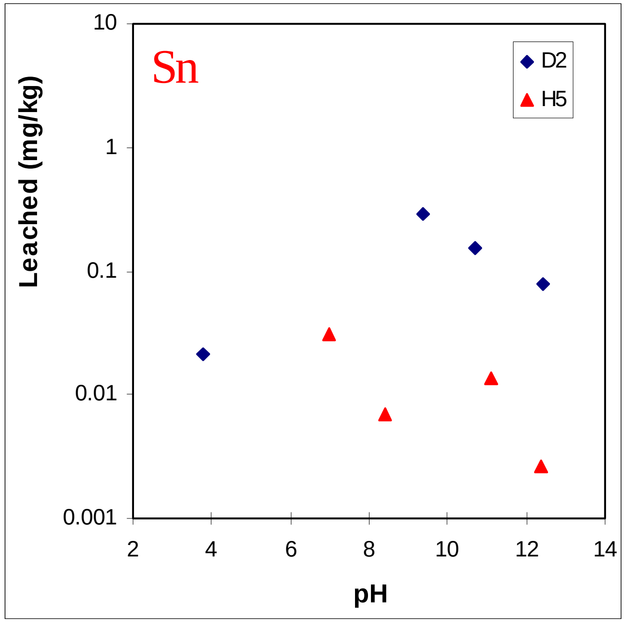

Cd
Leached mg/kg
1
0.1
0.01
0.001
0.0001
3
5
7
9
11
13
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

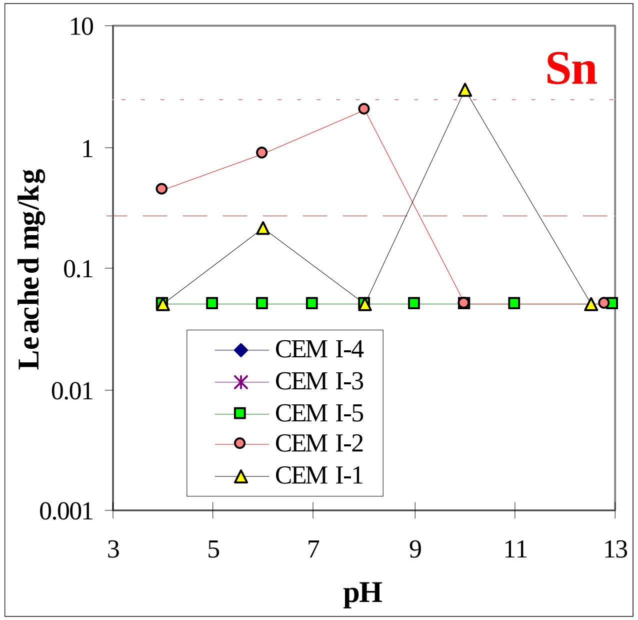

Cd
Leached mg/kg
1
0.1
0.01
0.001
0.0001
3
5
7
9
11
13
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

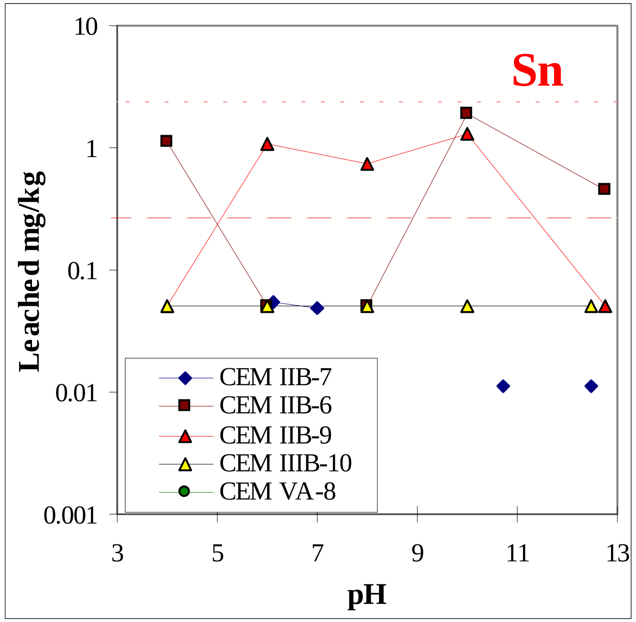

Cd
Leached mg/kg
1
0.1
0.01
0.001
0.0001
3
5
7
9
11
13
pH
SPCEM-12
SPCEM-11

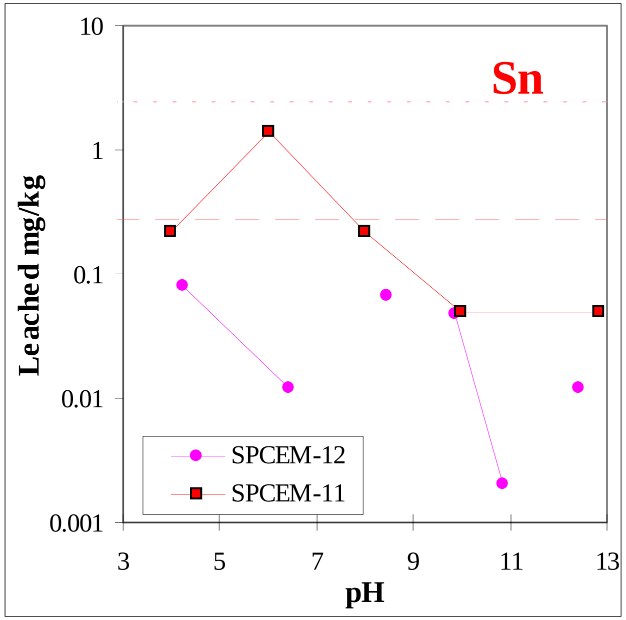

Sn
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

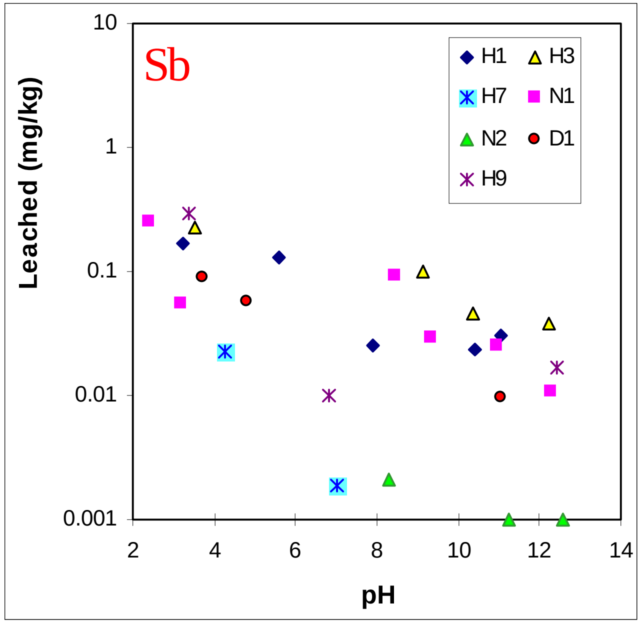

Sn
Leached (mg/kg)
pH
H6
W1
W2

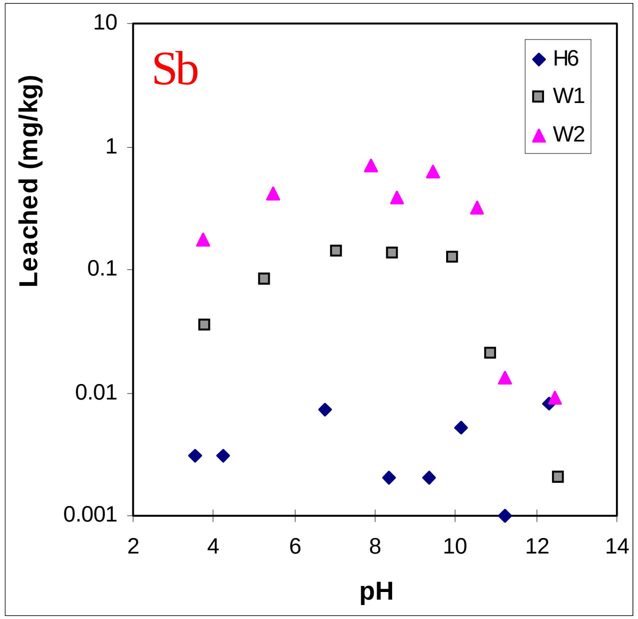

Sn
Leached (mg/kg)
pH
D2
H5

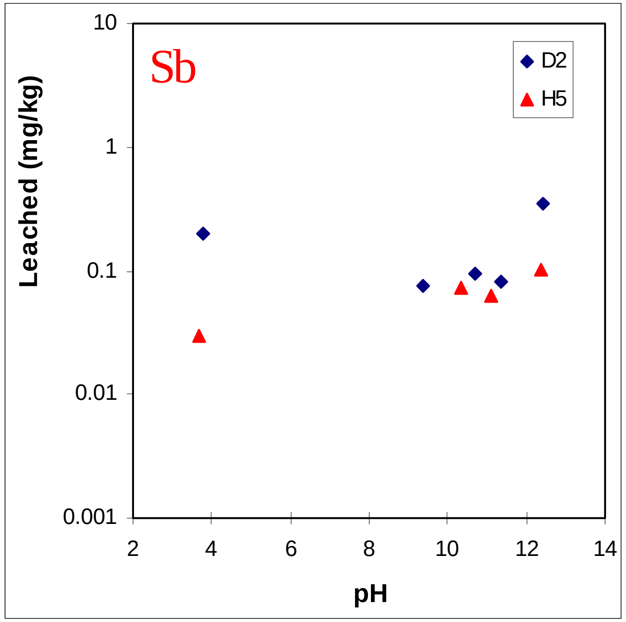

Sn
Leached mg/kg
pH
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

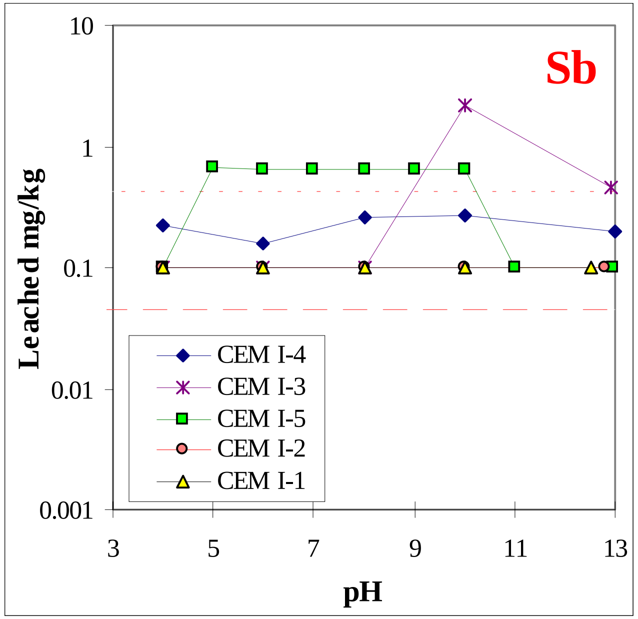

Sn
Leached mg/kg
pH
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

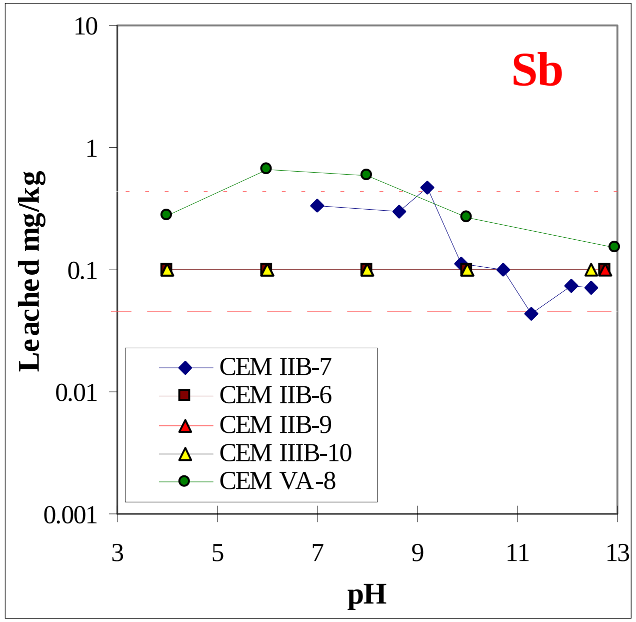

Sn
Leached mg/kg
pH
SPCEM-12
SPCEM-11

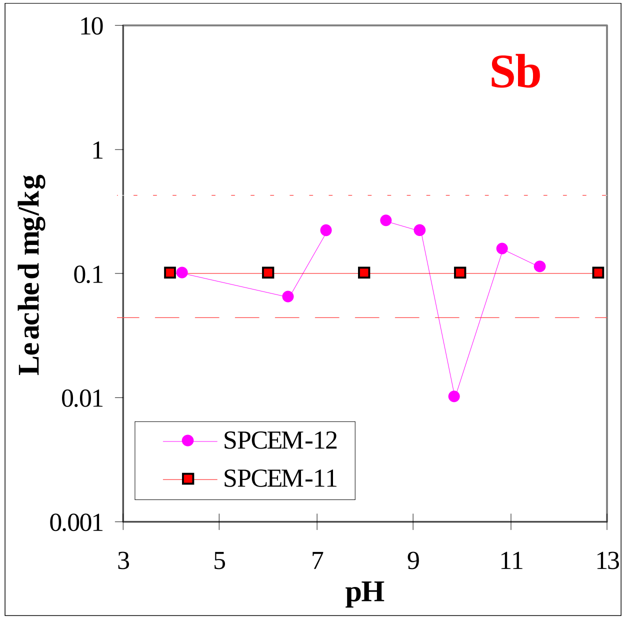

Sb
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9

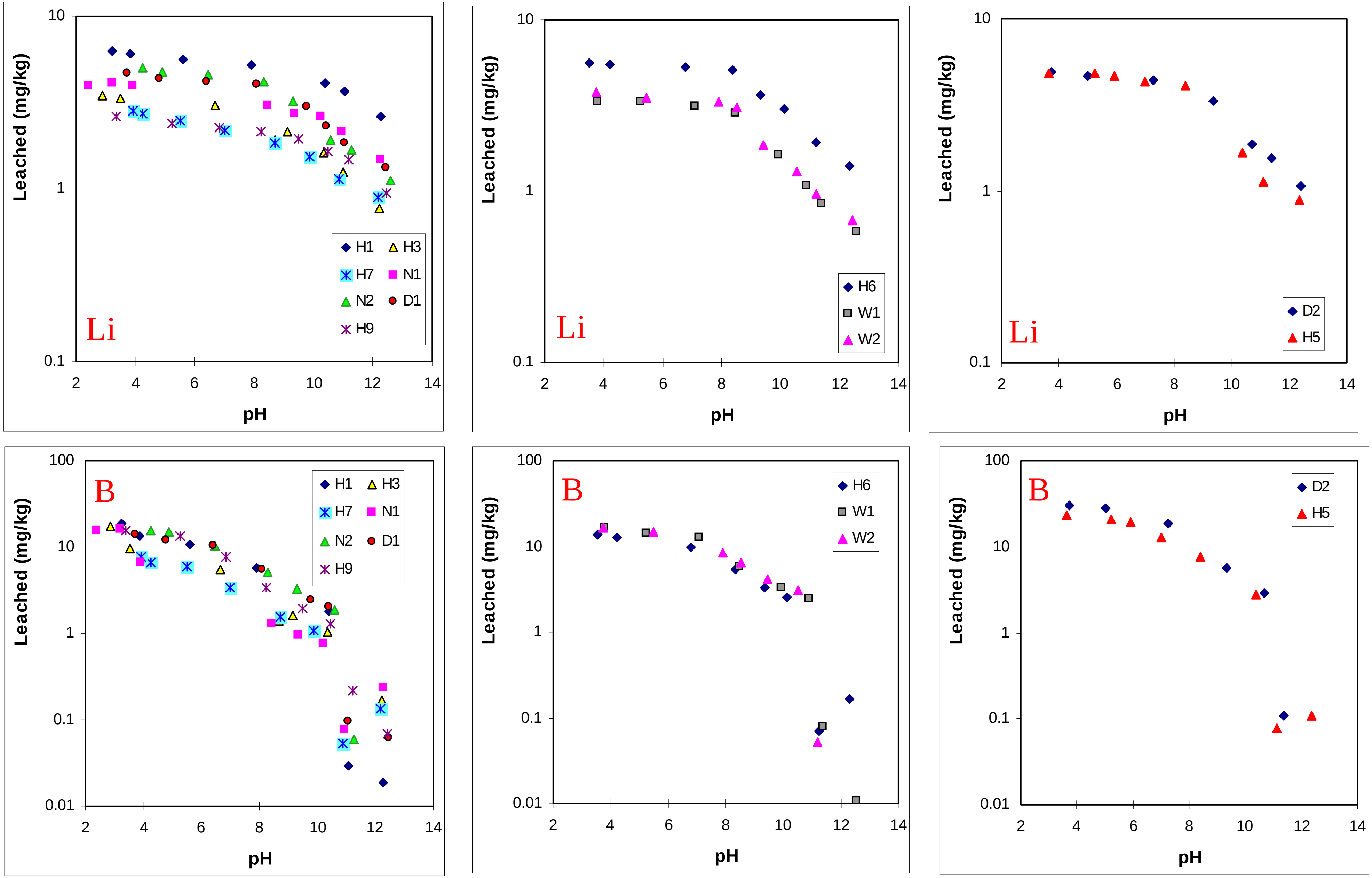

Sb
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H6
W1
W2

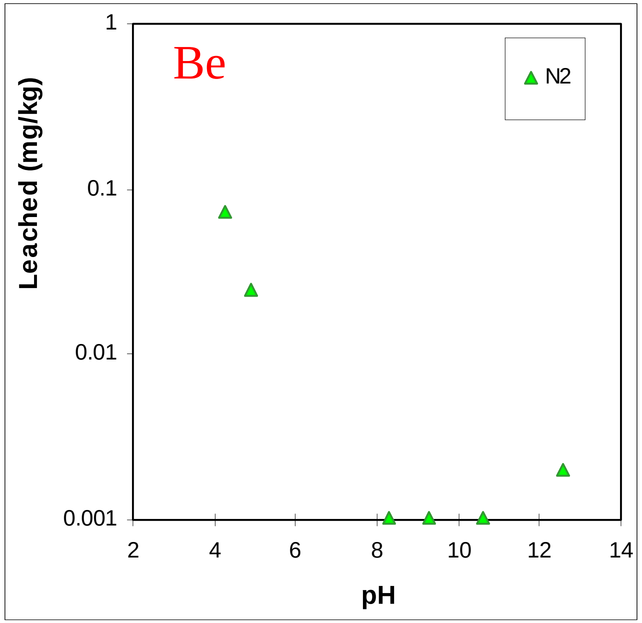

Sb
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
D2
H5

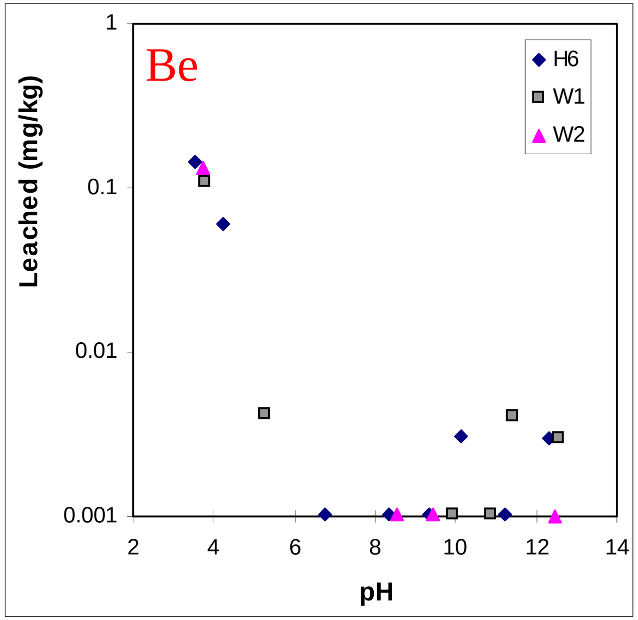

Sb
Leached mg/kg
pH
10
1
0.1
0.01
0.001
3
5
7
9
11
13
CEM I-4
CEM I-3
CEM I-5
CEM I-2
CEM I-1

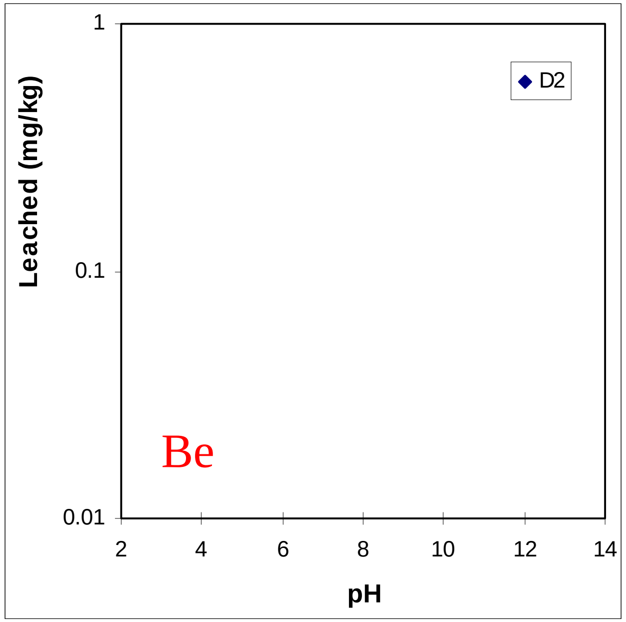

Sb
Leached mg/kg
pH
10
1
0.1
0.01
0.001
3
5
7
9
11
13
CEM IIB-7
CEM IIB-6
CEM IIB-9
CEM IIIB-10
CEM VA-8

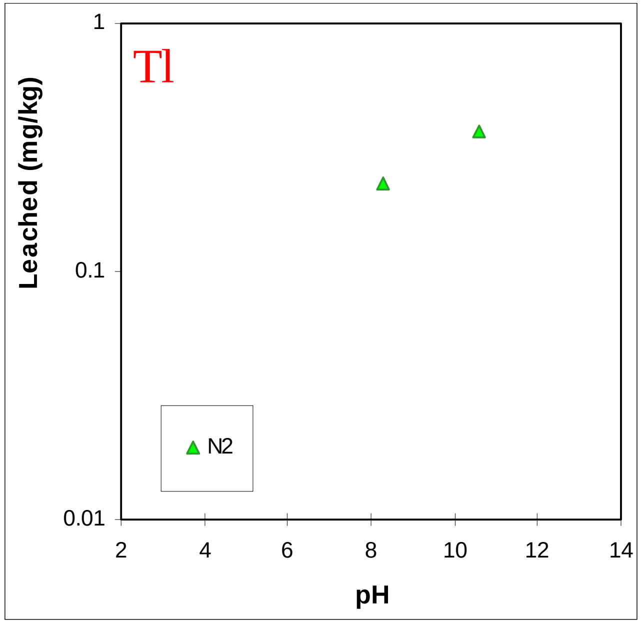

Sb
Leached mg/kg
pH
10
1
0.1
0.01
0.001
3
5
7
9
11
13
SPCEM-12
SPCEM-11

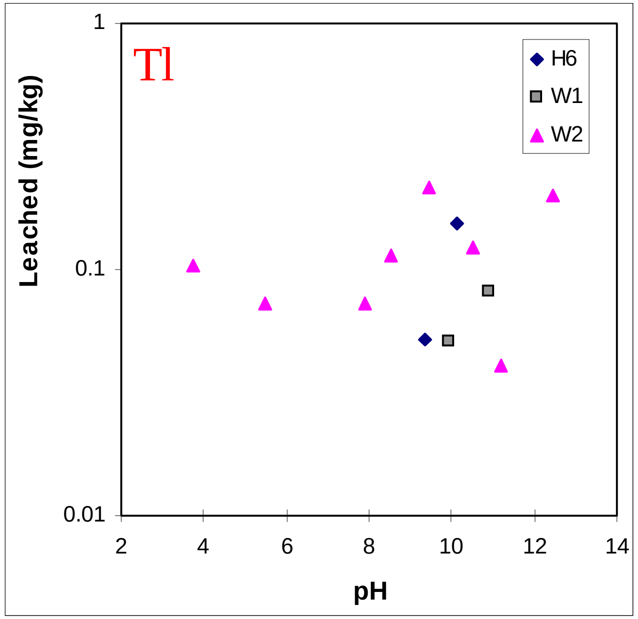

Li
Leached (mg/kg)
pH
10
1
0.1
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
Li
Leached (mg/kg)
pH
H6
W1
W2
Li
Leached (mg/kg)
pH
D2
H5
B
Leached (mg/kg)
pH
100
10
1
0.1
0.01
H1
H3
H7
N1
N2
D1
H9
B
Leached (mg/kg)
pH
H6
W1
W2
B
Leached (mg/kg)
pH
D2
H5

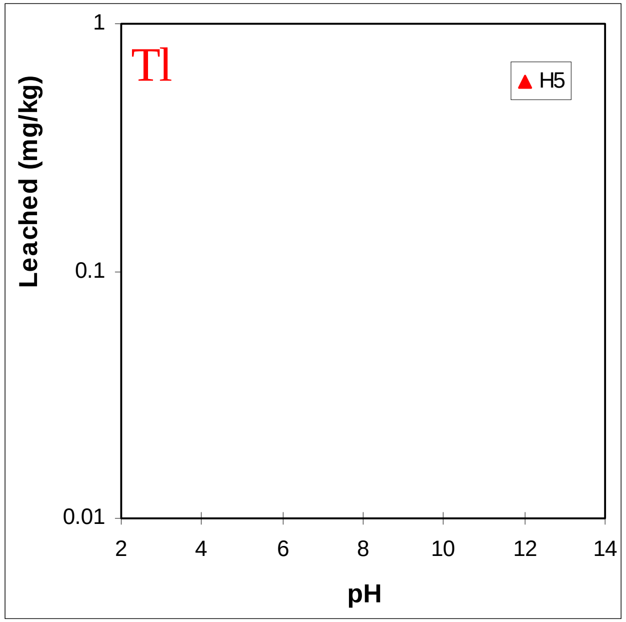

Be
N2
Leached (mg/kg)
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH


Be
H6
W1
W2
Leached (mg/kg)
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH

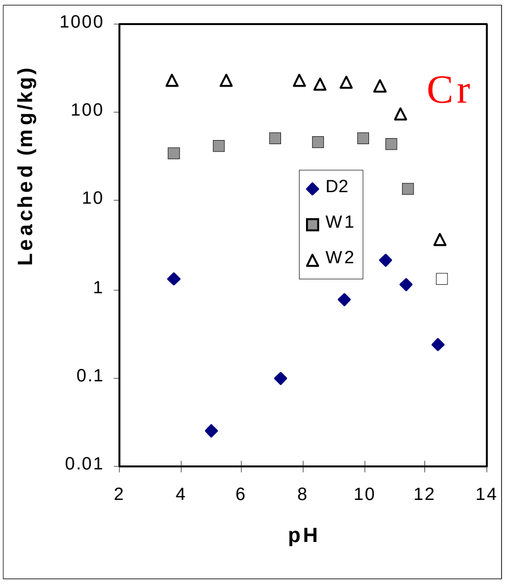

Be
D2
Leached (mg/kg)
1
0.1
0.01
2
4
6
8
10
12
14
pH

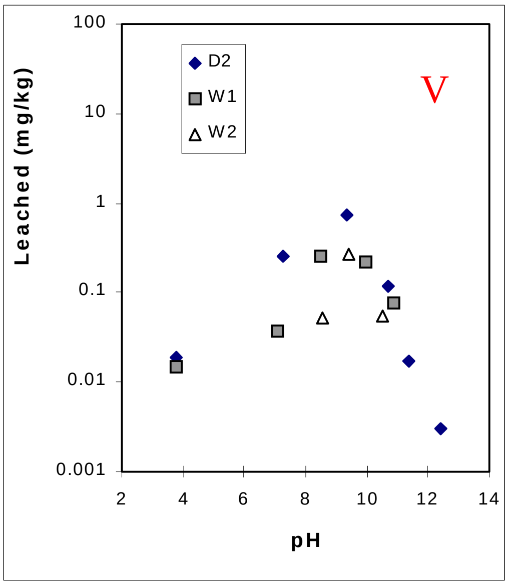

Tl
N2
Leached (mg/kg)
1
0.1
0.01
2
4
6
8
10
12
14
pH

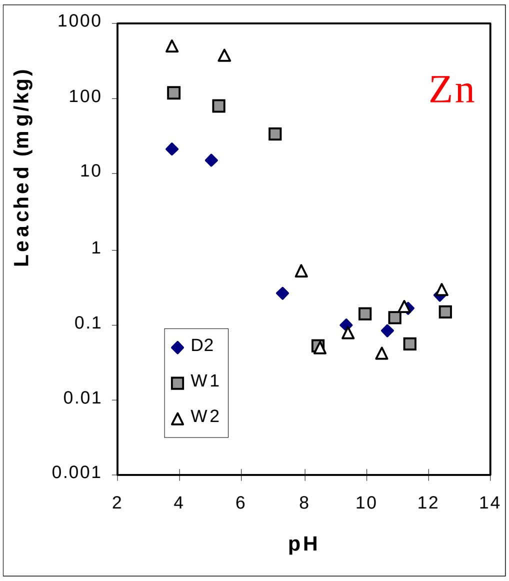

Tl
H6
W1
W2
Leached (mg/kg)
1
0.1
0.01
2
4
6
8
10
12
14
pH

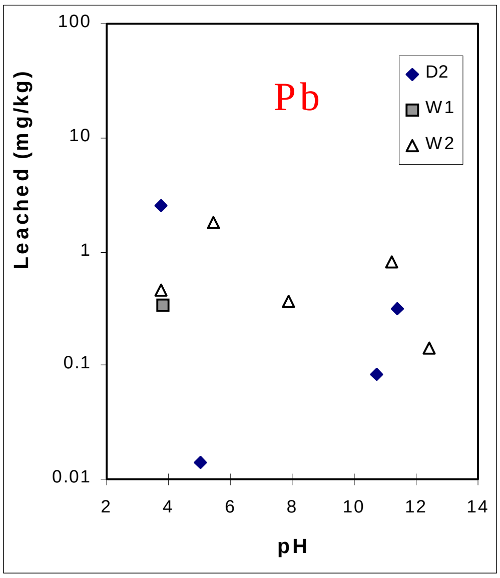

Tl
H5
Leached (mg/kg)
1
0.1
0.01
2
4
6
8
10
12
14
pH

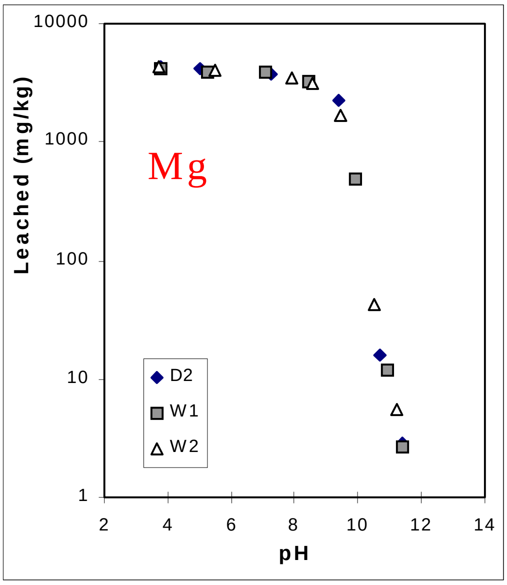
ANNEX 8 pH DEPENDENCE TEST DATA - COMPARISON OF D2, W1 AND W2 (same meal composition).

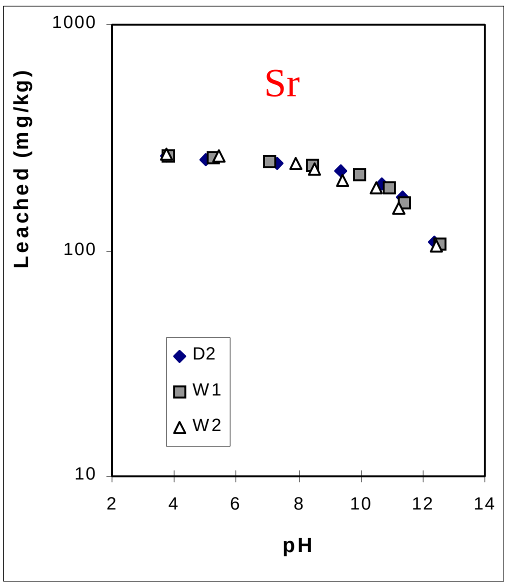


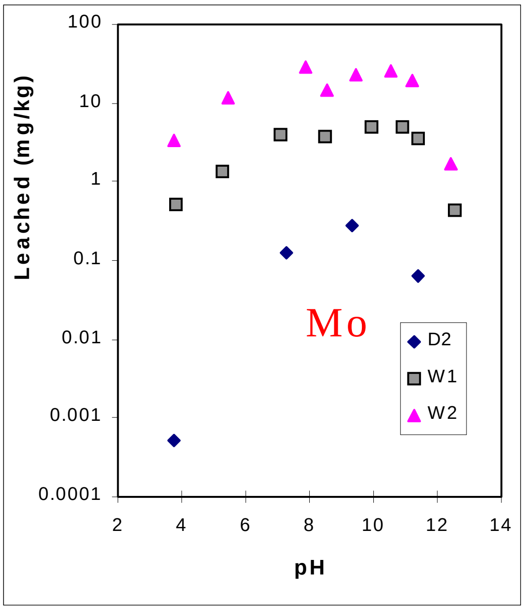


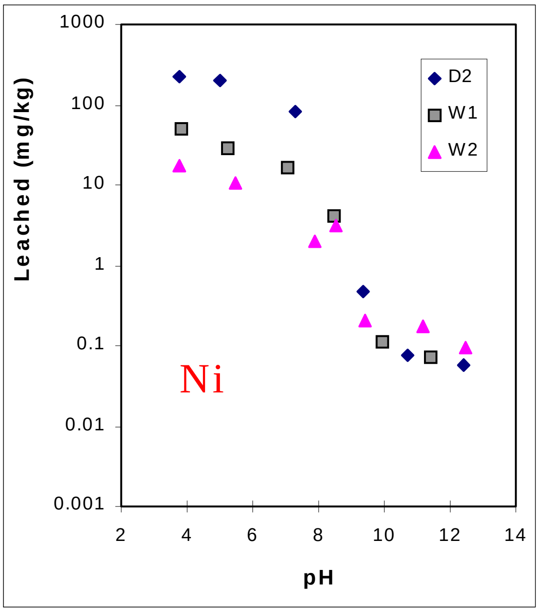


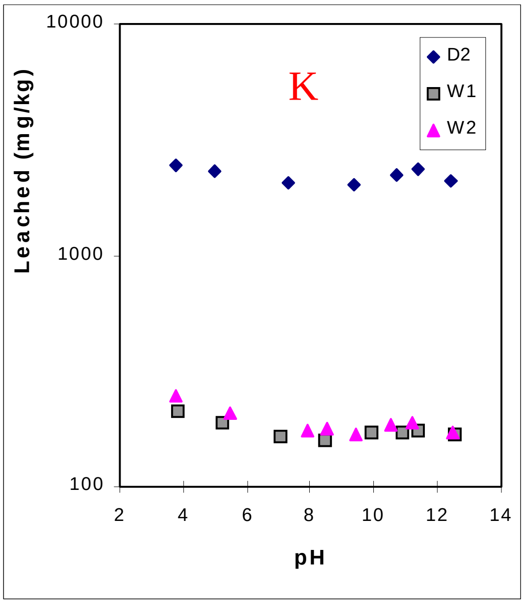


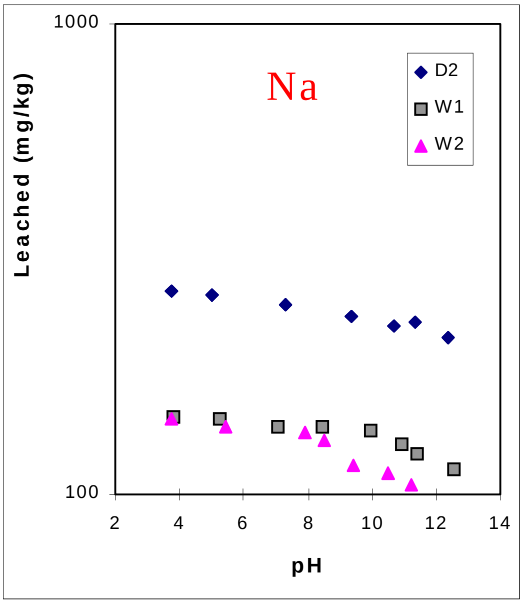


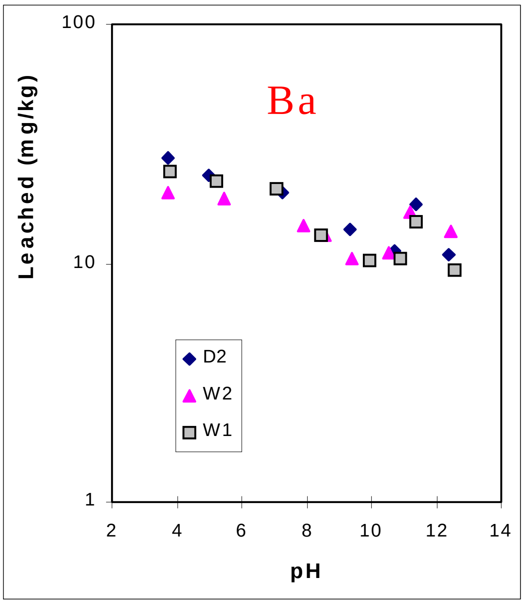


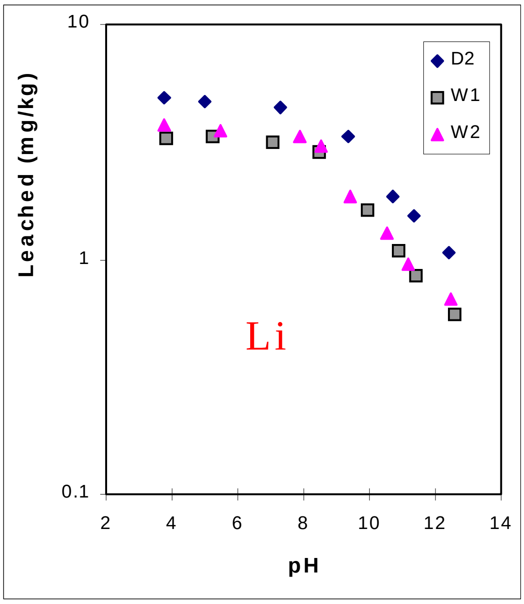

Mo
Leached (mg/kg)
100
10
1
0.1
0.01
0.001
0.0001
2 4 6 8 10 12 14
pH
D2
W1
W2


Ni
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14
pH
D2
W1
W2

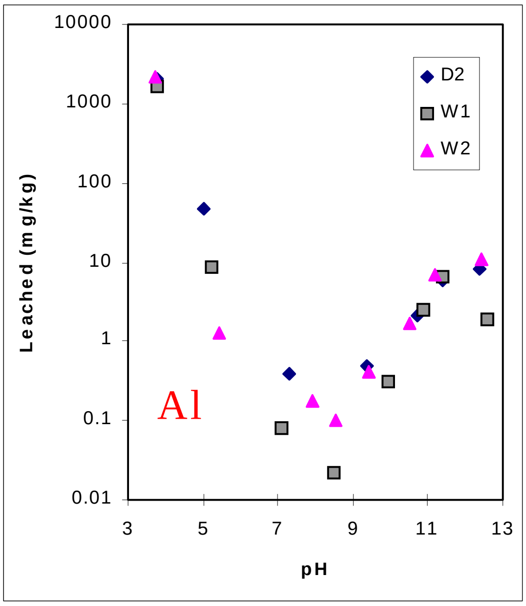

K
Leached (mg/kg)
10000
1000
100
2 4 6 8 10 12 14
pH
D2
W1
W2

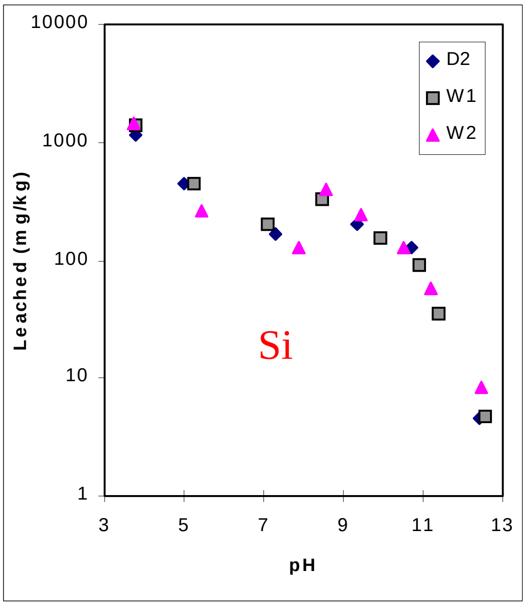

Na
Leached (mg/kg)
1000
100
2 4 6 8 10 12 14
pH
D2
W1
W2

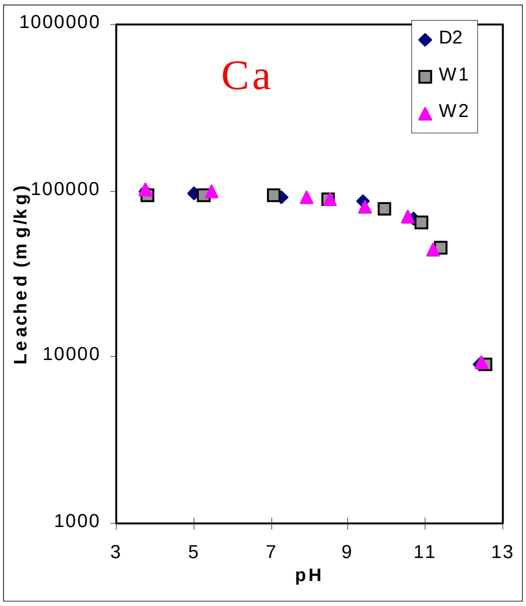

Ba
Leached (mg/kg)
100
10
1
2 4 6 8 10 12 14
pH
D2
W2
W1

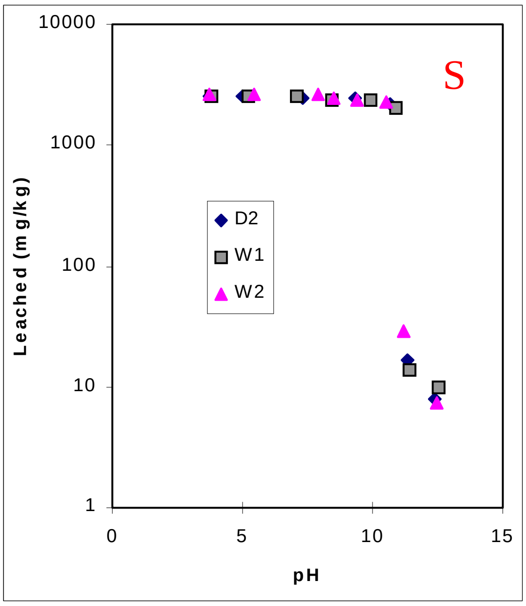

Li
Leached (mg/kg)
10
1
0.1
2 4 6 8 10 12 14
pH
D2
W1
W2

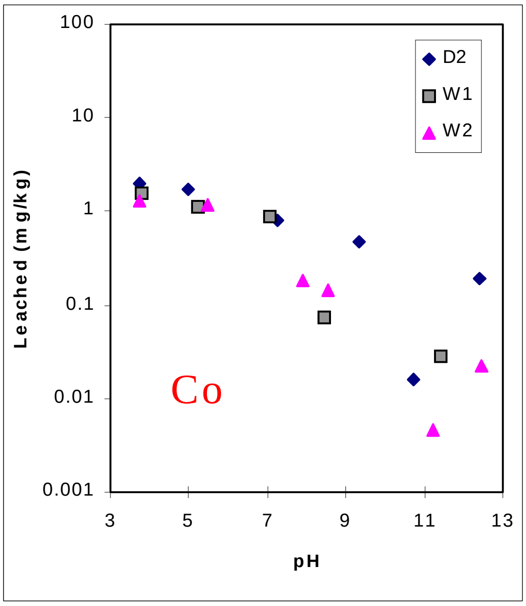
ANNEX 8 pH DEPENDENCE TEST DATA - COMPARISON OF D2, W1 AND W2

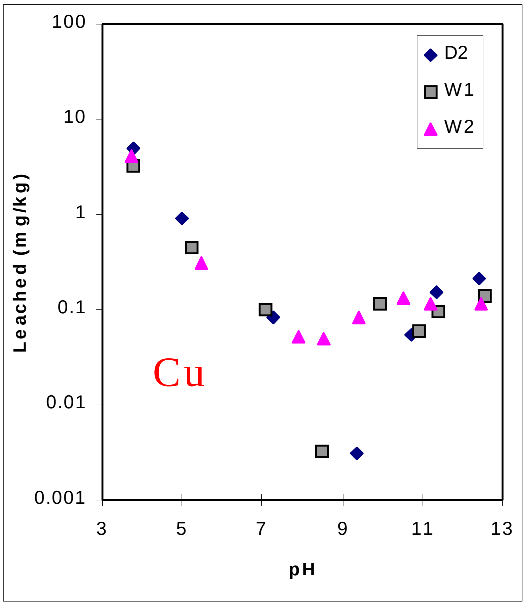


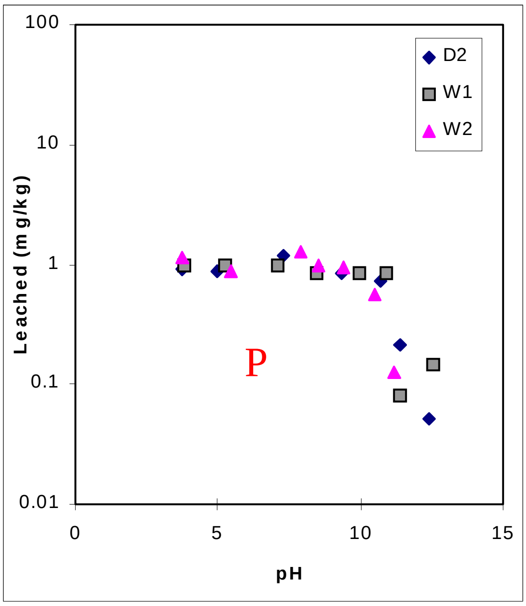


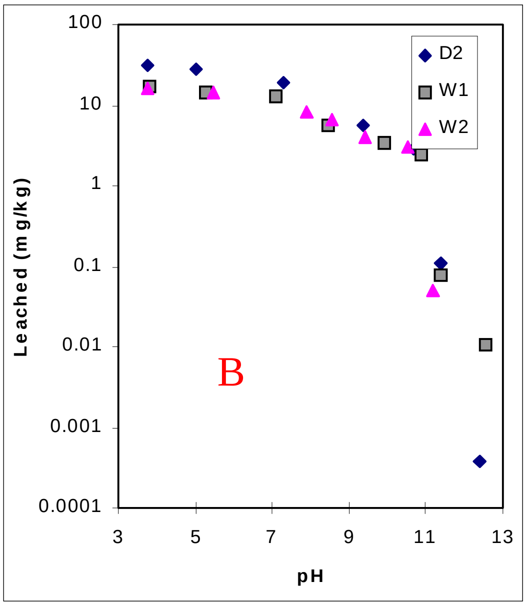


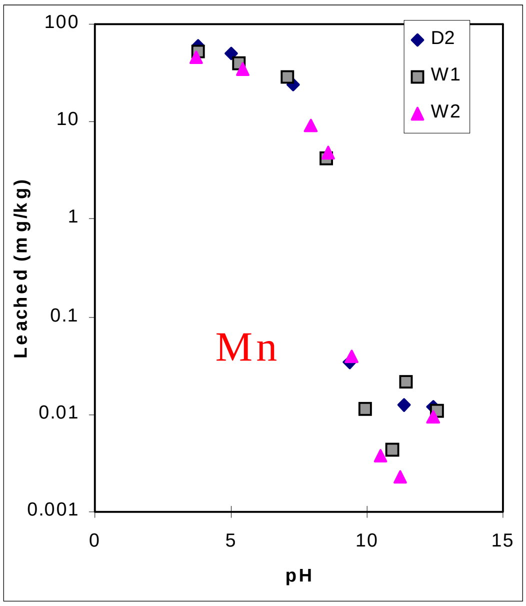


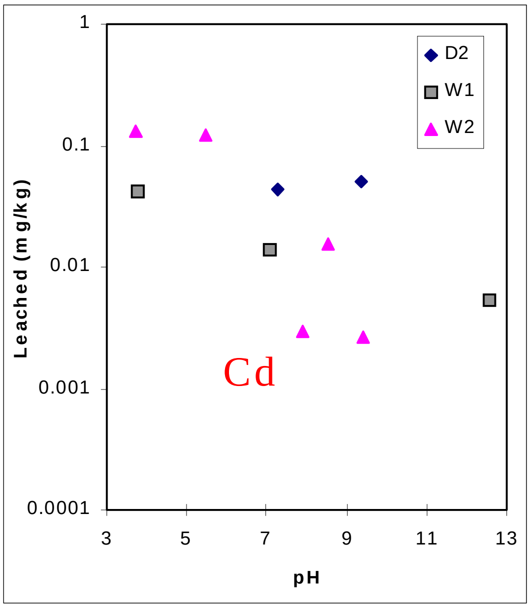


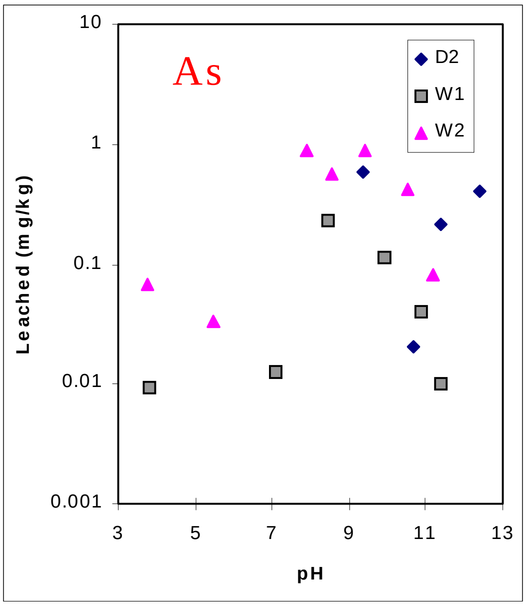


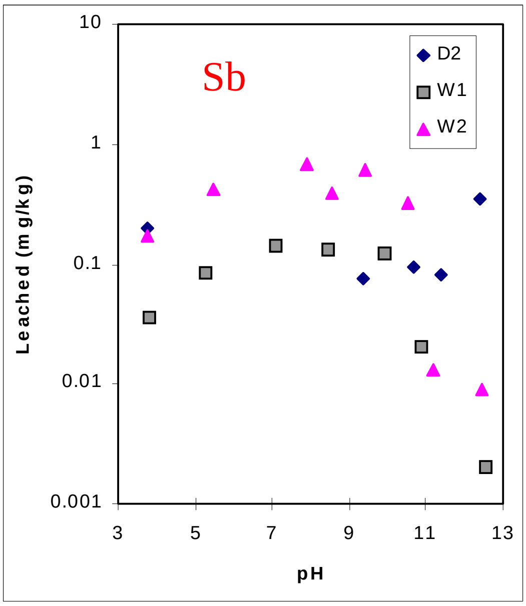

P
Leached (mg/kg)
pH
D2
W1
W2


B
Leached (mg/kg)
pH
D2
W1
W2

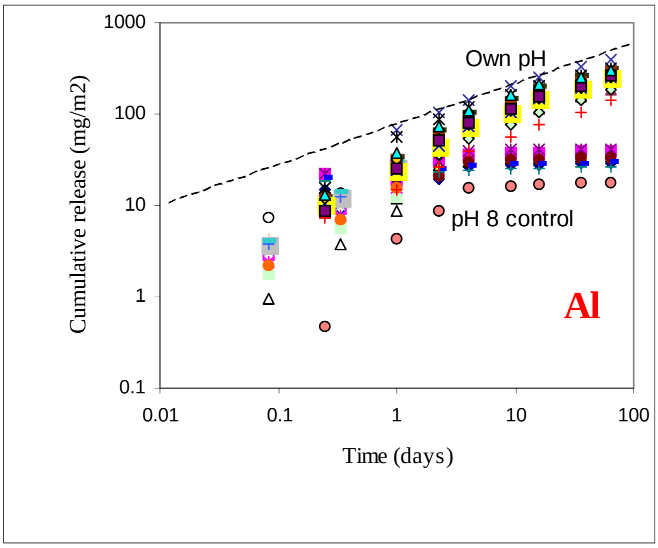

Mn
Leached (mg/kg)
pH
D2
W1
W2

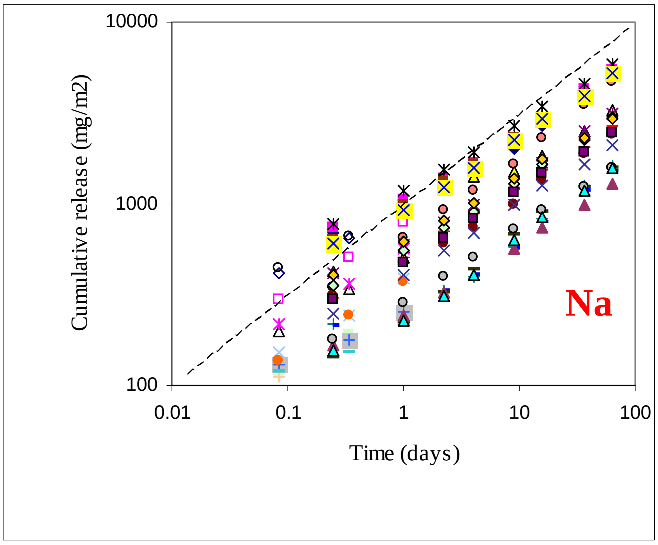

Cd
Leached (mg/kg)
pH
D2
W1
W2

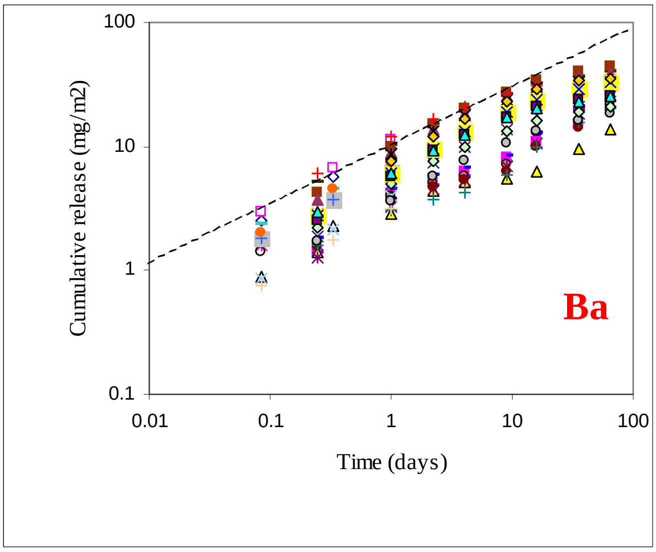

As
Leached (mg/kg)
pH
D2
W1
W2

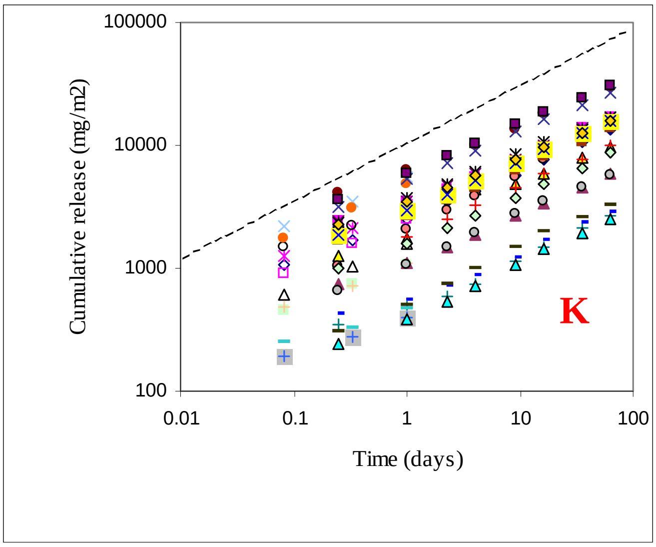

Sb
Leached (mg/kg)
pH
D2
W1
W2

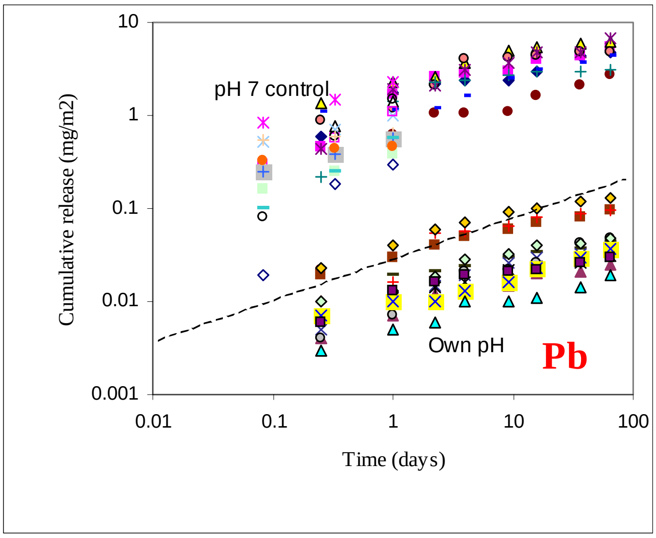
ANNEX 9 TANK LEACH TEST DATA (Own pH, imposed neutral pH and compliance test data)

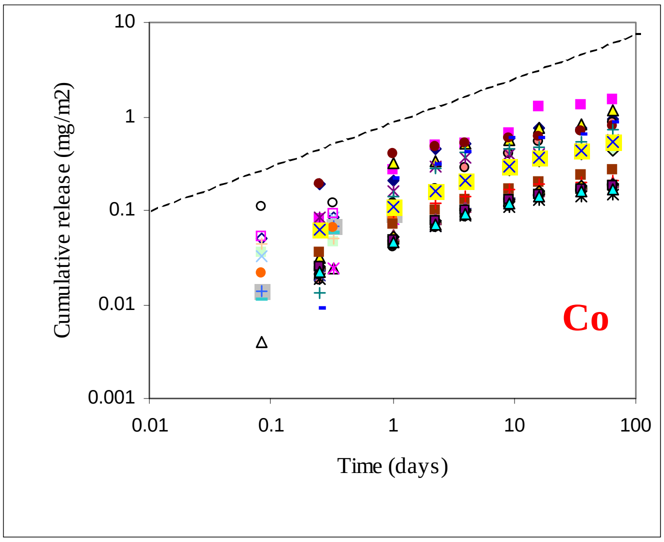


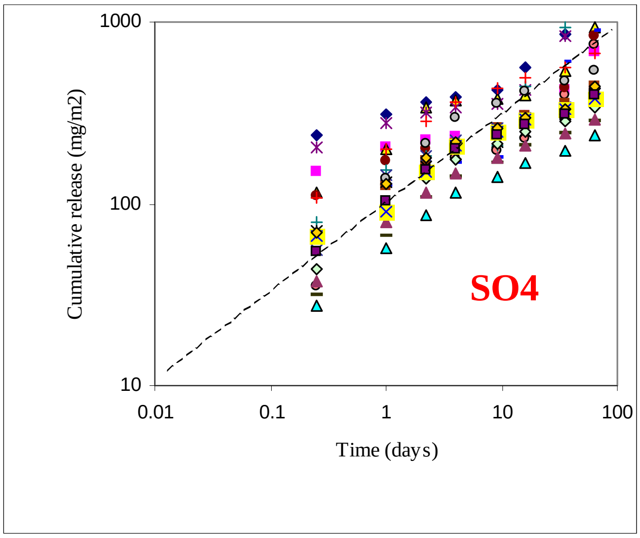


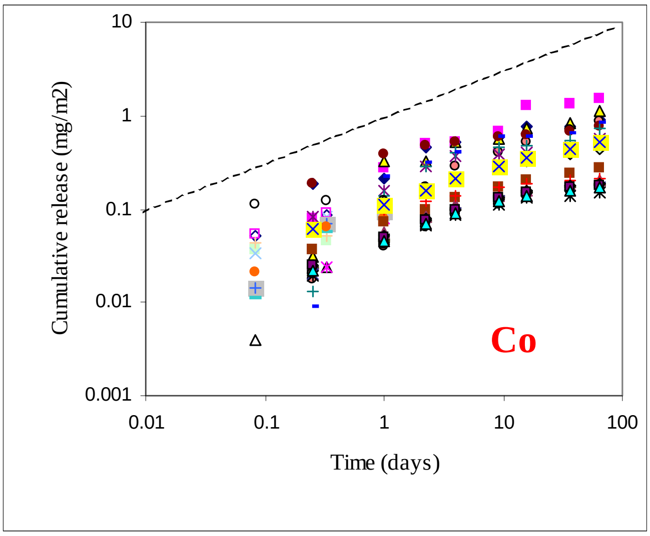


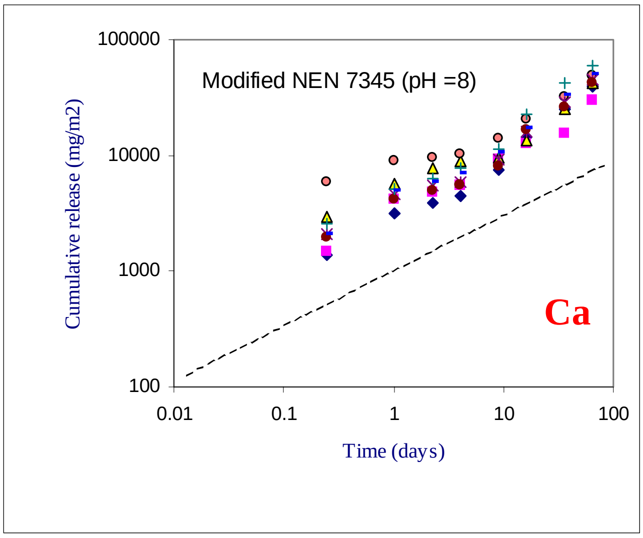


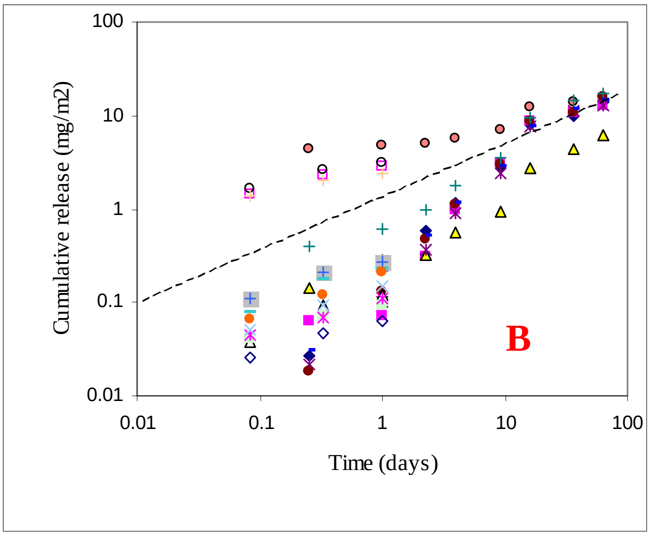


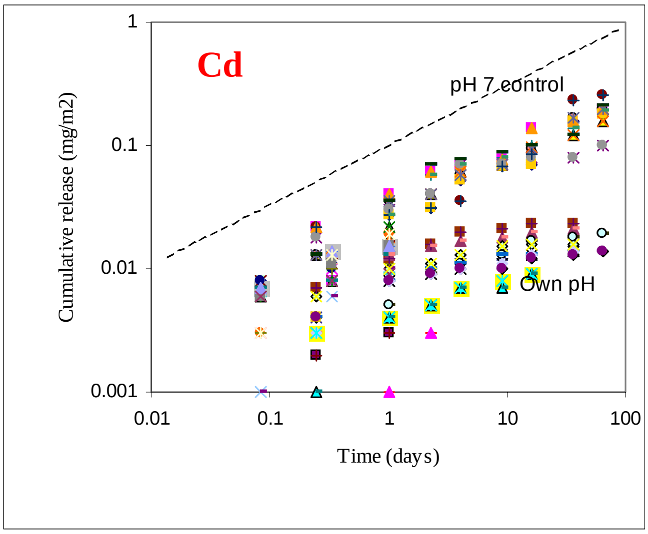


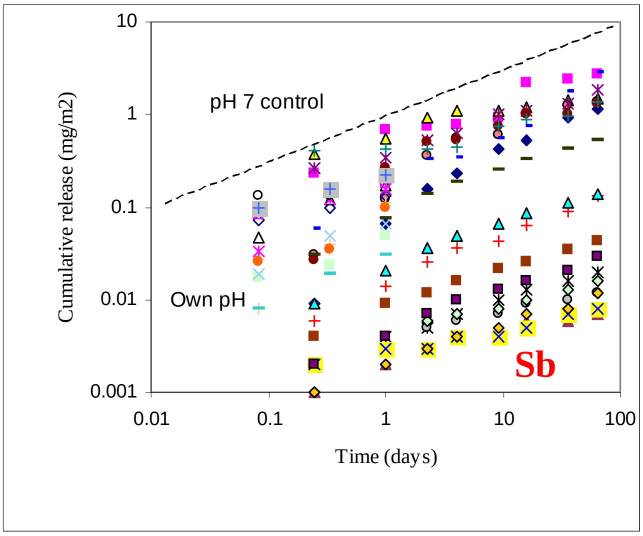

SO4
Cumulative release (mg/m2)
1000
100
10
0.01
0.1
1
10
100
Time (days)

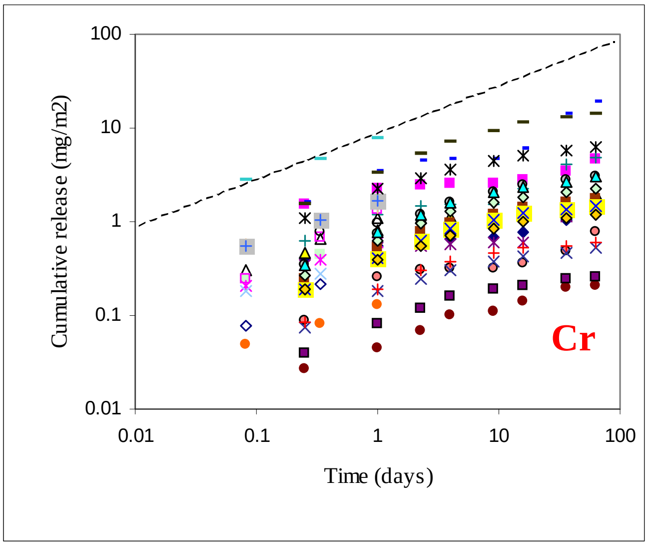

Co
Cumulative release (mg/m2)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Time (days)

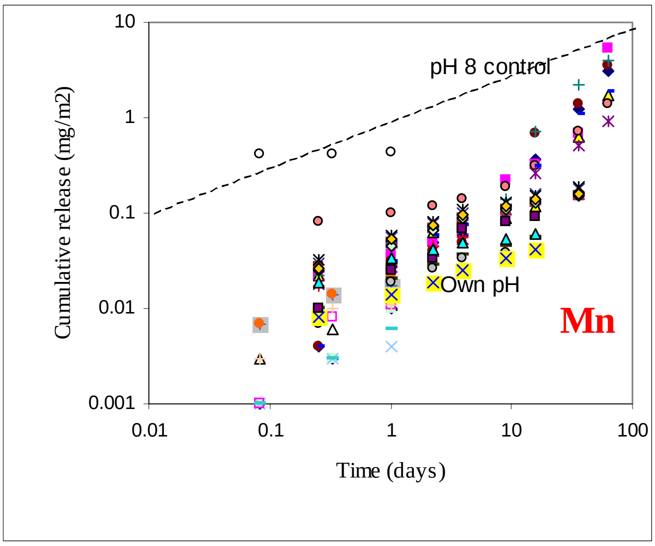

Modified NEN 7345 (pH =8)
Ca
Cumulative release (mg/m2)
100000
10000
1000
100
0.01
0.1
1
10
100
Time (days)

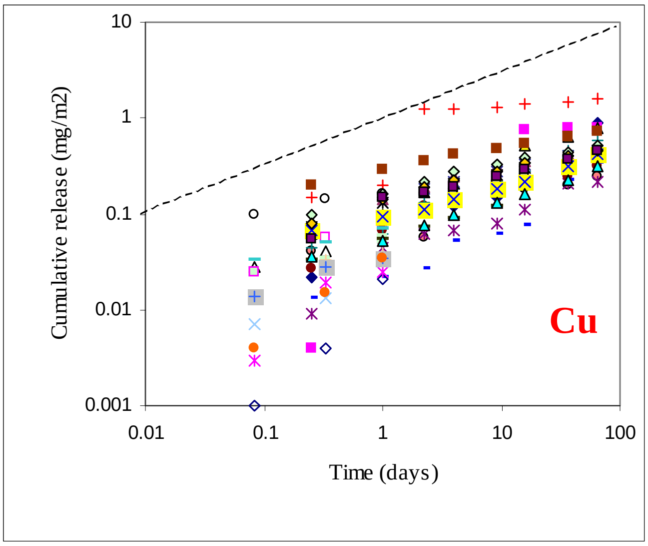

B
Cumulative release (mg/m2)
100
10
1
0.1
0.01
0.01
0.1
1
10
100
Time (days)

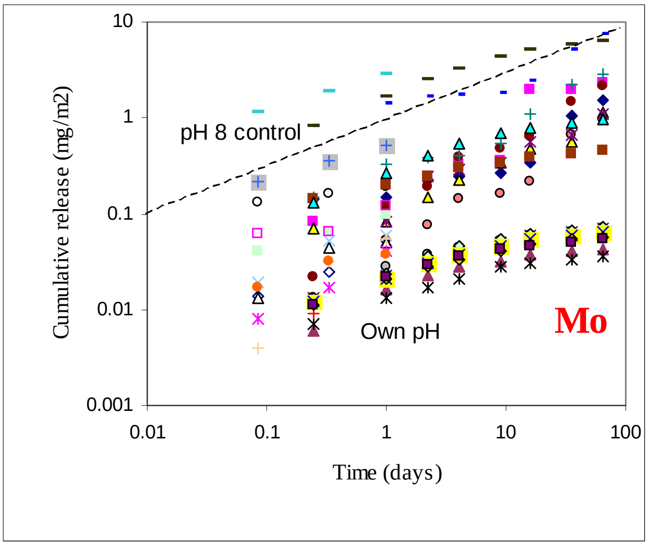

Cd
pH 7 control
Own pH
Cumulative release (mg/m2)
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Time (days)

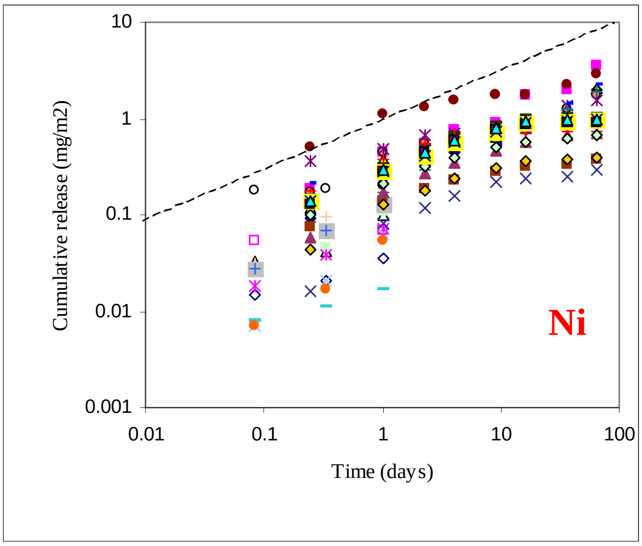

pH 7 control
Own pH
Sb
Cumulative release (mg/m2)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Time (days)

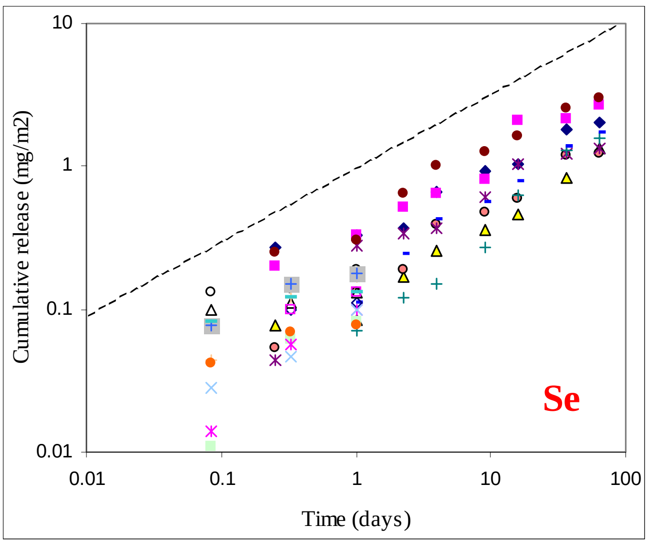

Cumulative release (mg/m2)
Time (days)
Cr


Cumulative release (mg/m2)
Time (days)
pH 8 control
Own pH
Mn

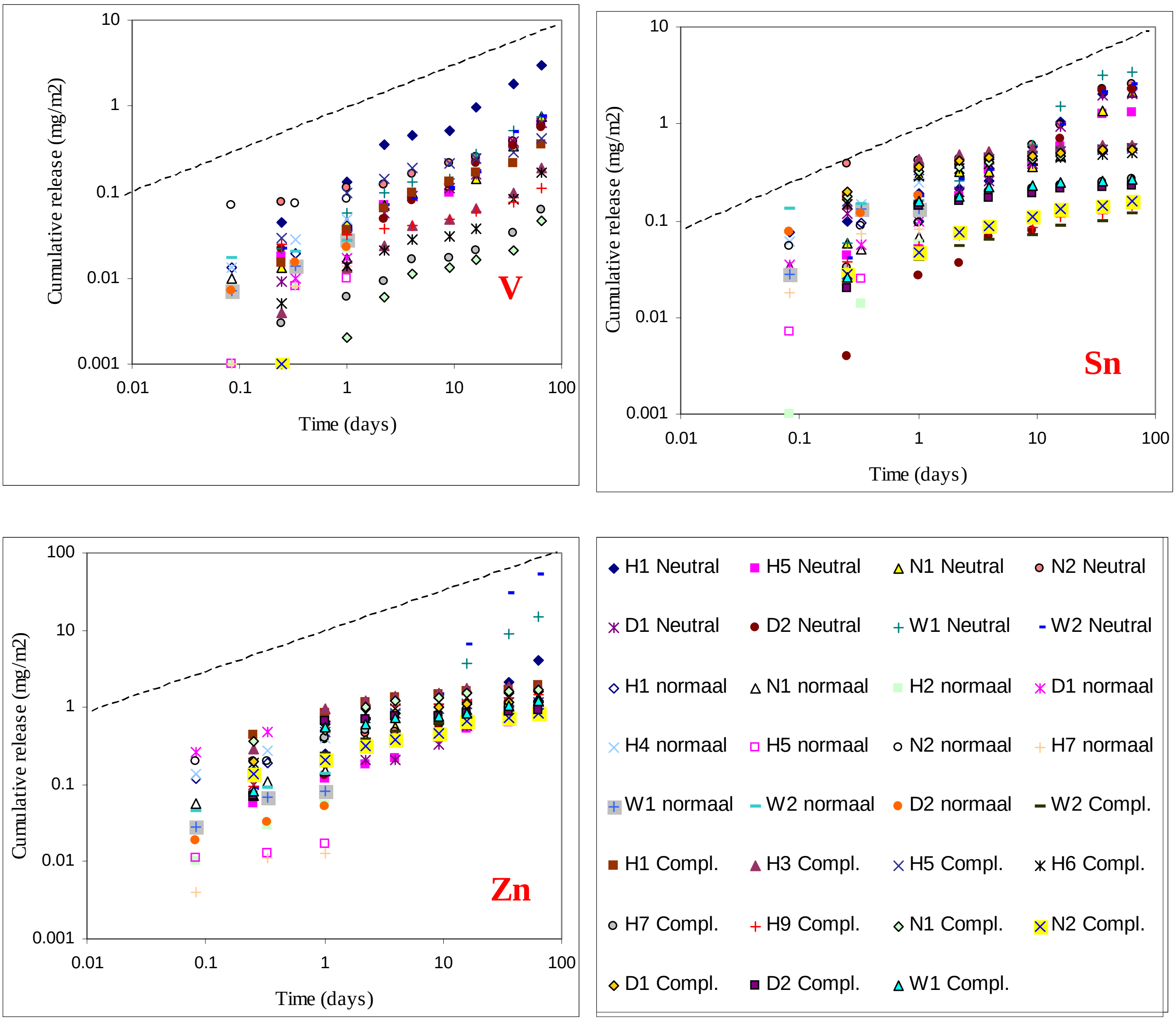

Cumulative release (mg/m2)
Time (days)
Cu


Cumulative release (mg/m2)
Time (days)
pH 8 control
Own pH
Mo

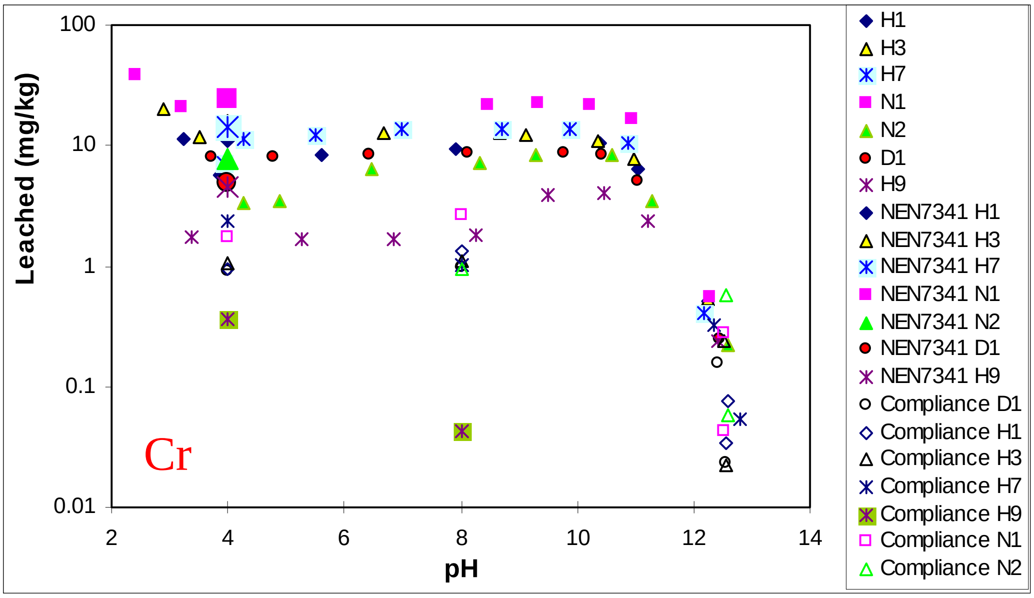

Cumulative release (mg/m2)
Time (days)
Ni

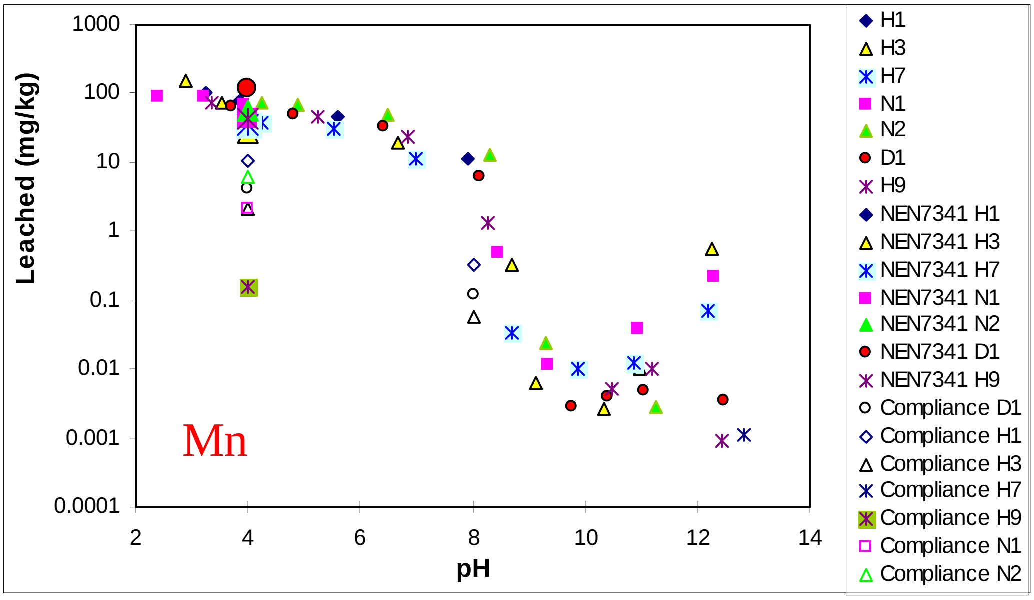

Cumulative release (mg/m2)
Time (days)
Se

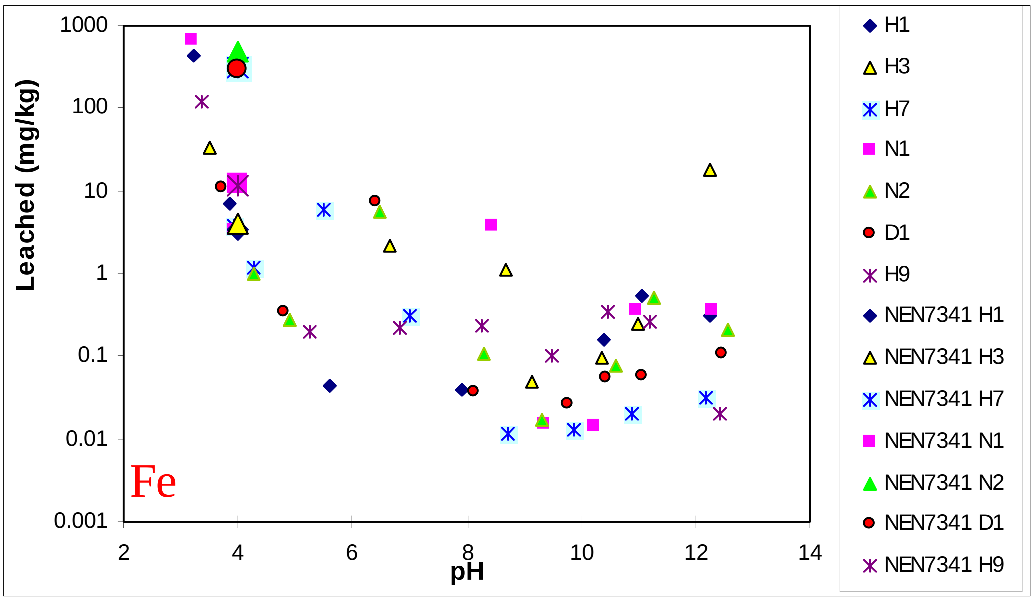
ANNEX 9 TANK LEACH TEST DATA (Own pH, imposed neutral pH and compliance test data)

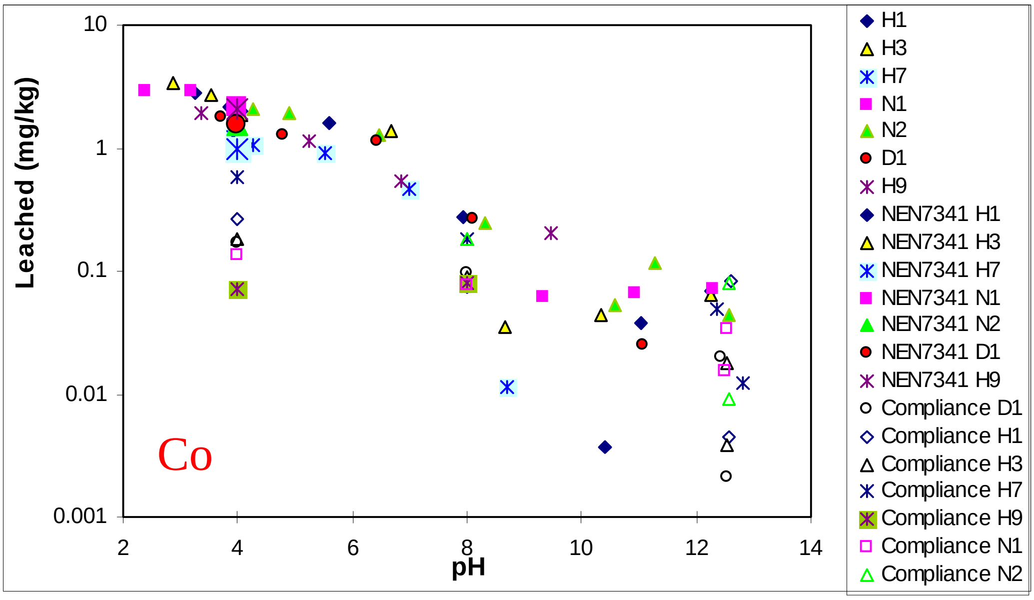


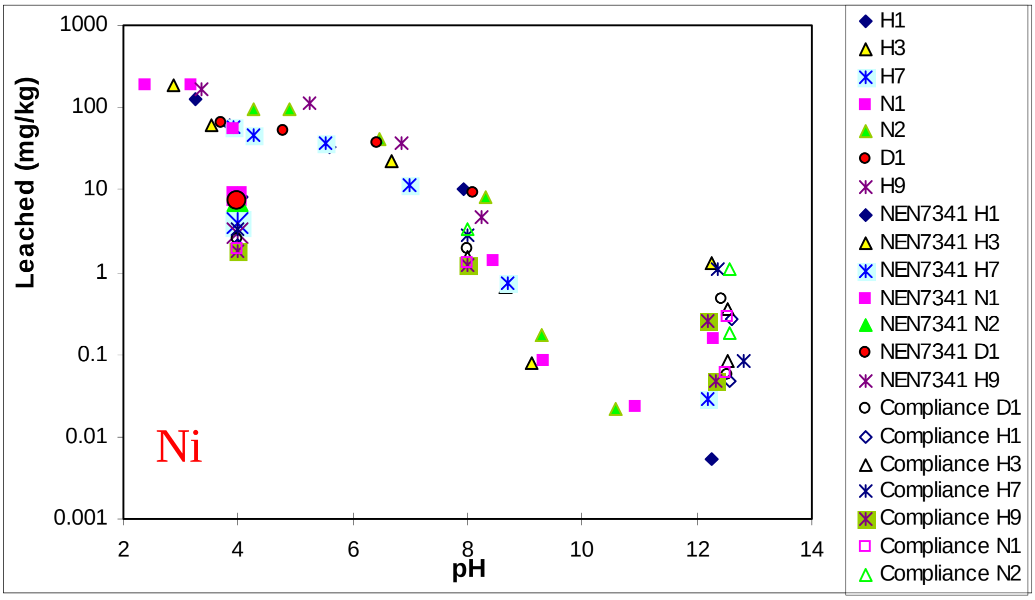
ANNEX 10 Comparison of compliance and availability test data with pH stat test (particle size pH stat: <2 mm; NEN 7341: <125 µm; compliance test: <10 mm)

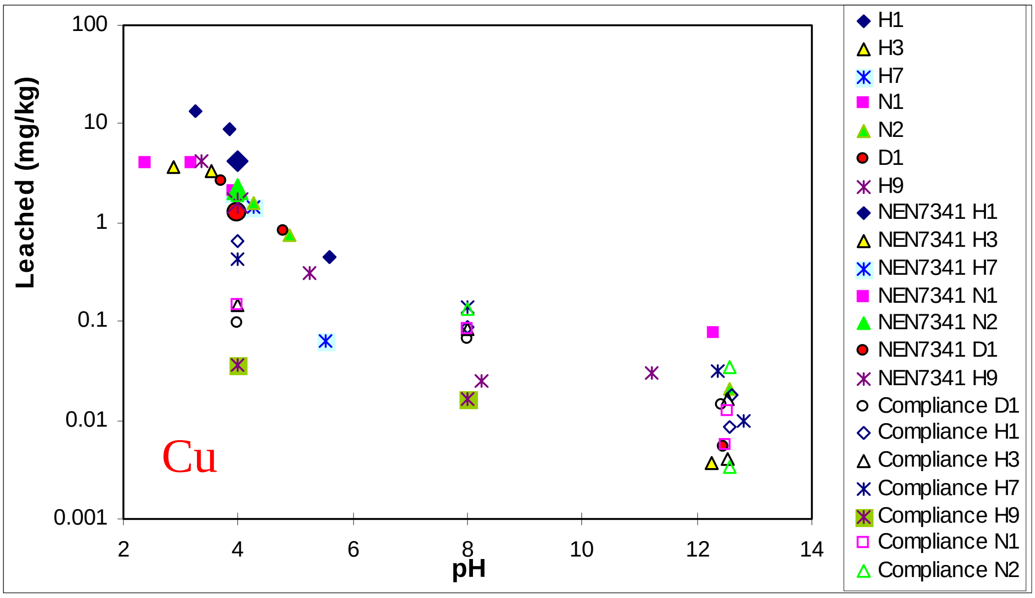


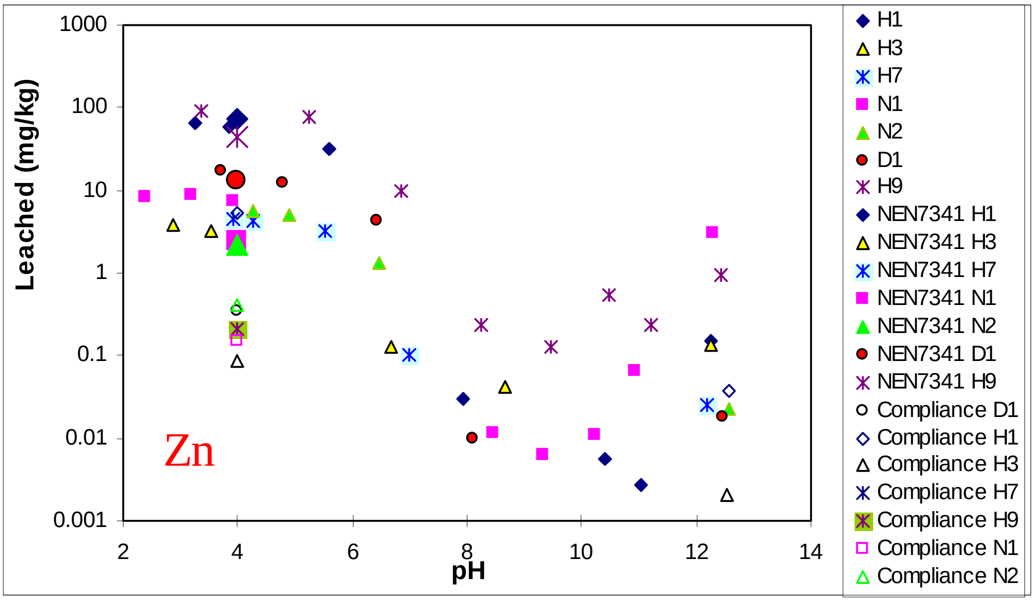


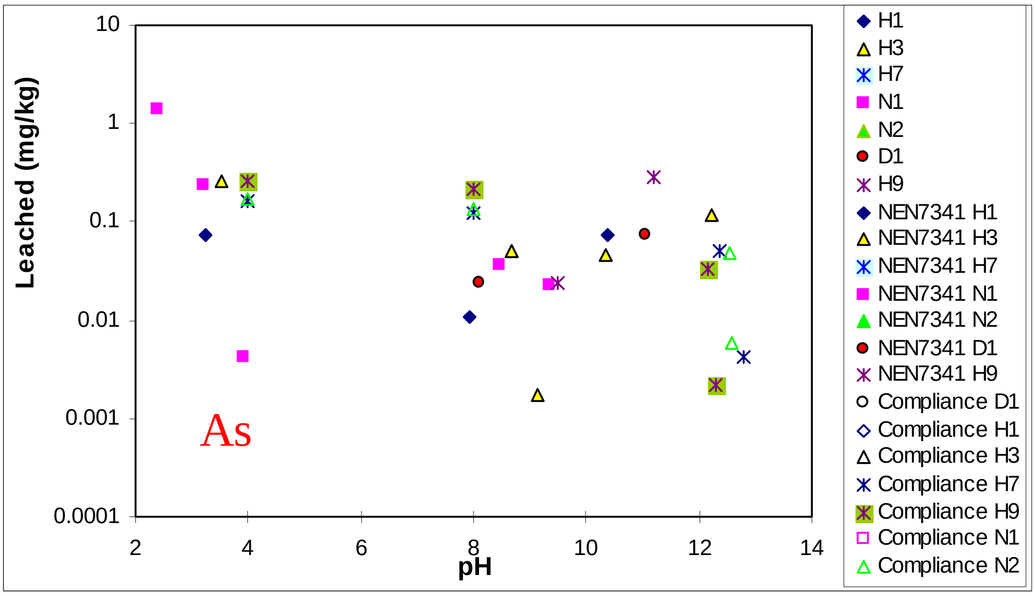


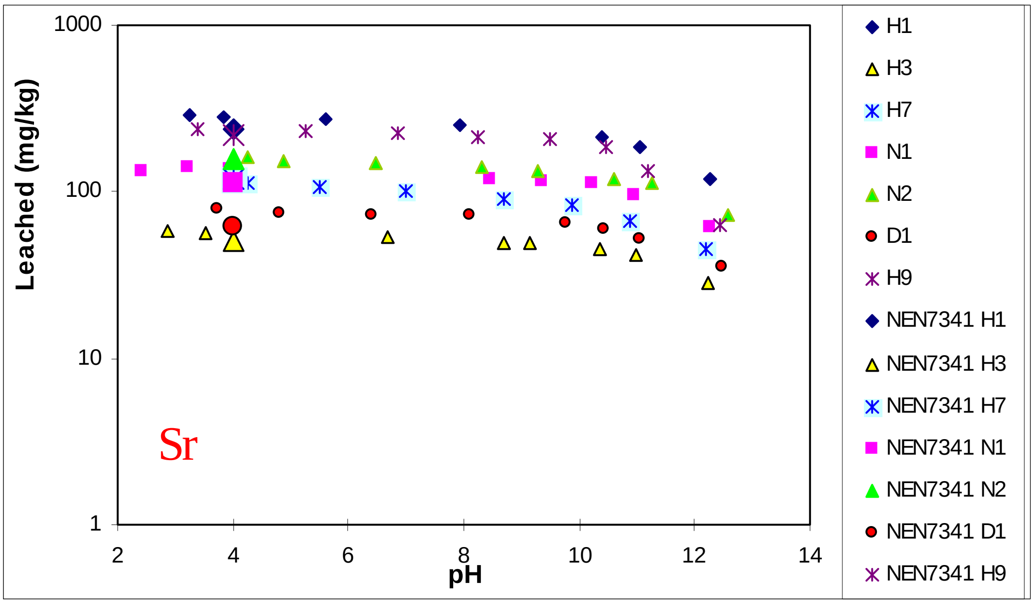

Co
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

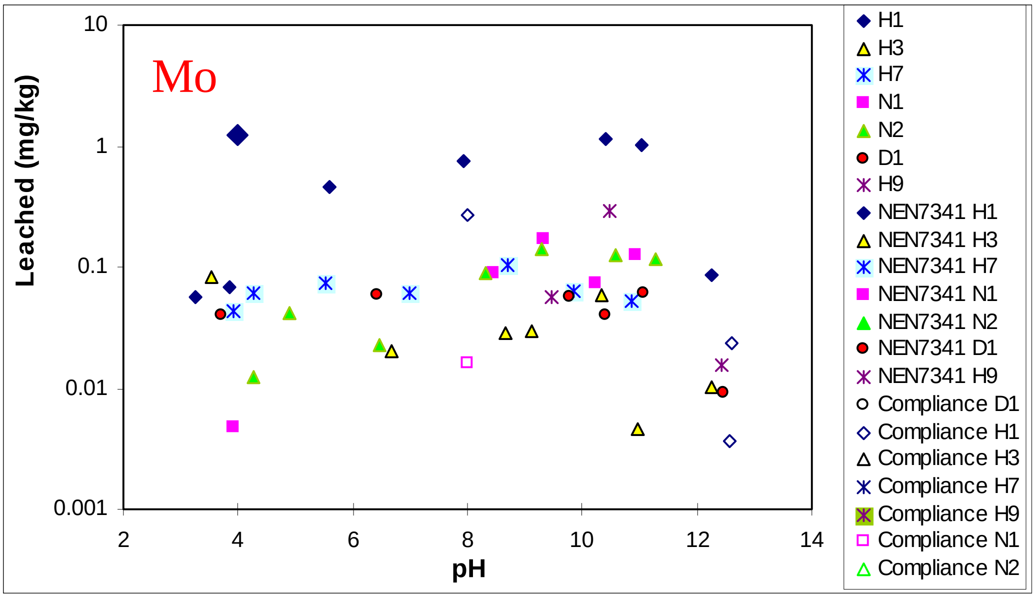

Ni
Leached (mg/kg)
pH
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

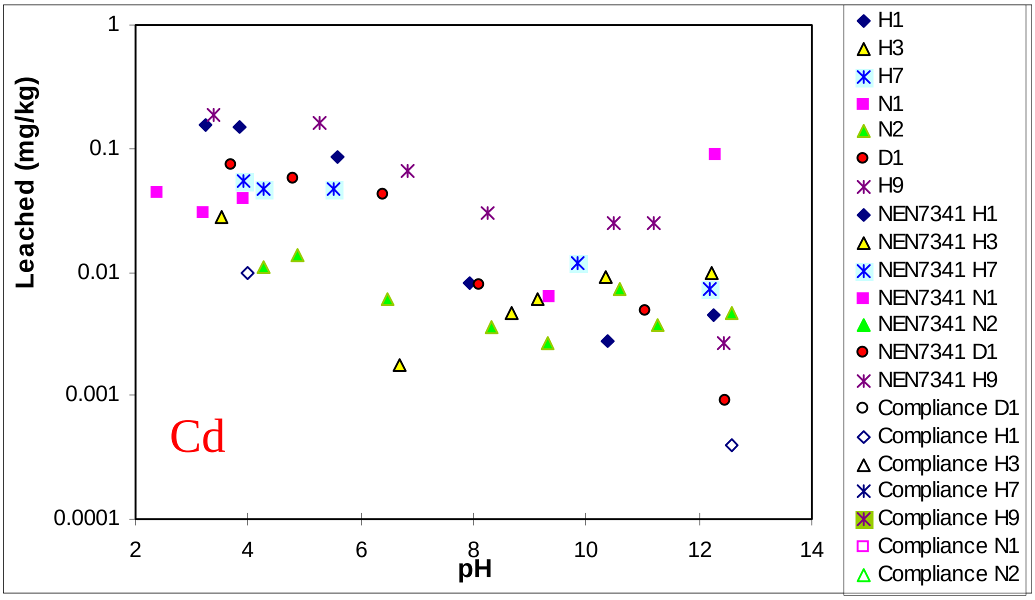

Cu
Leached (mg/kg)
pH
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

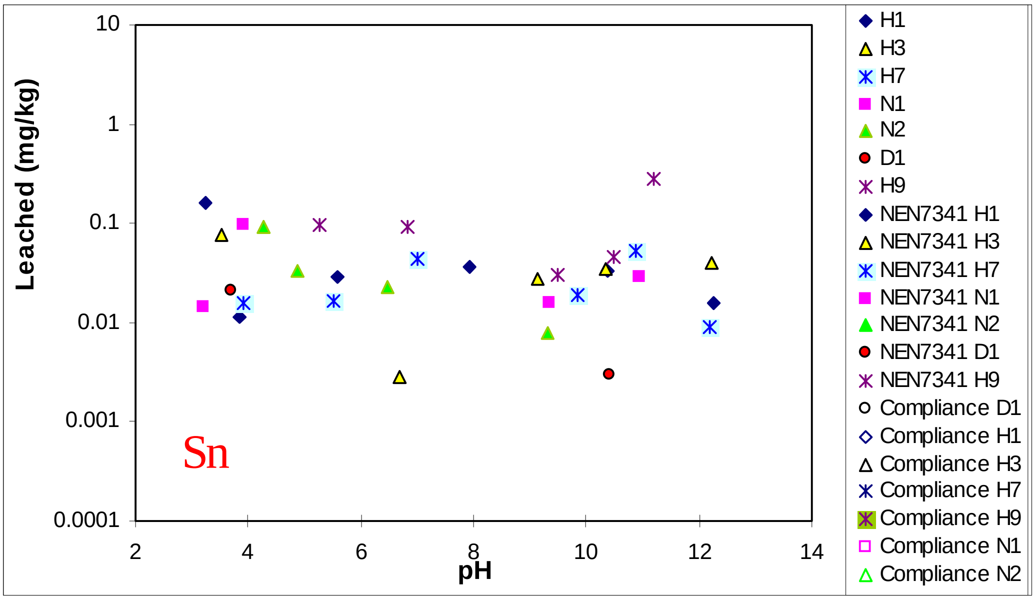

Zn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

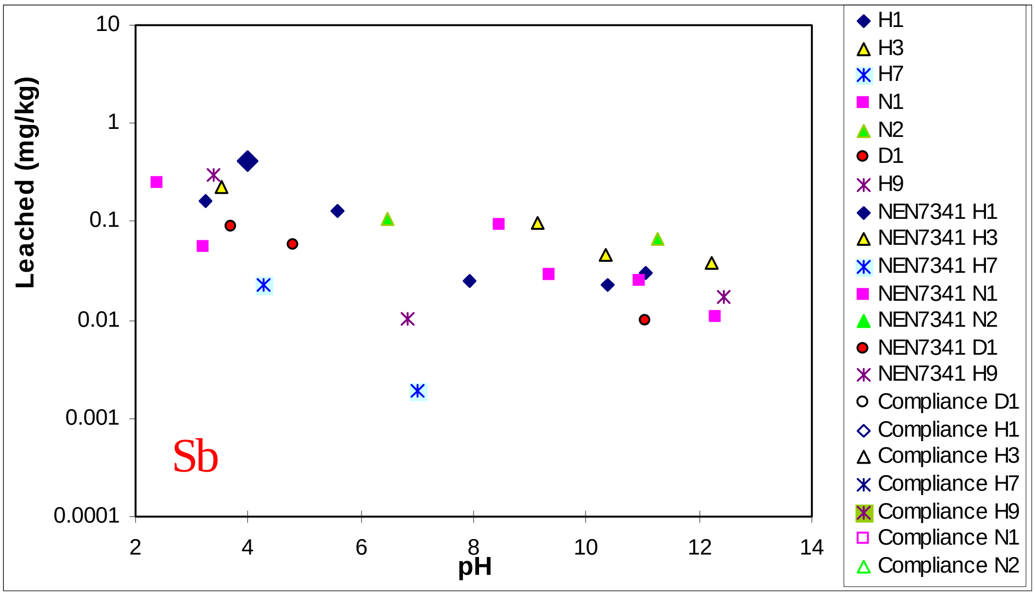

As
Leached (mg/kg)
10
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

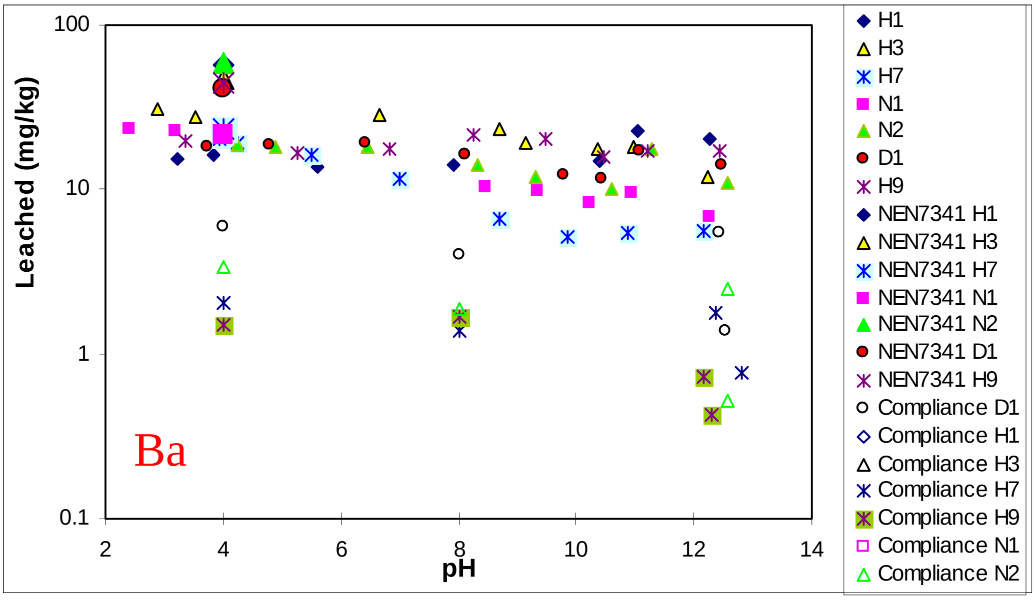

Sr
Leached (mg/kg)
1000
100
10
1
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9

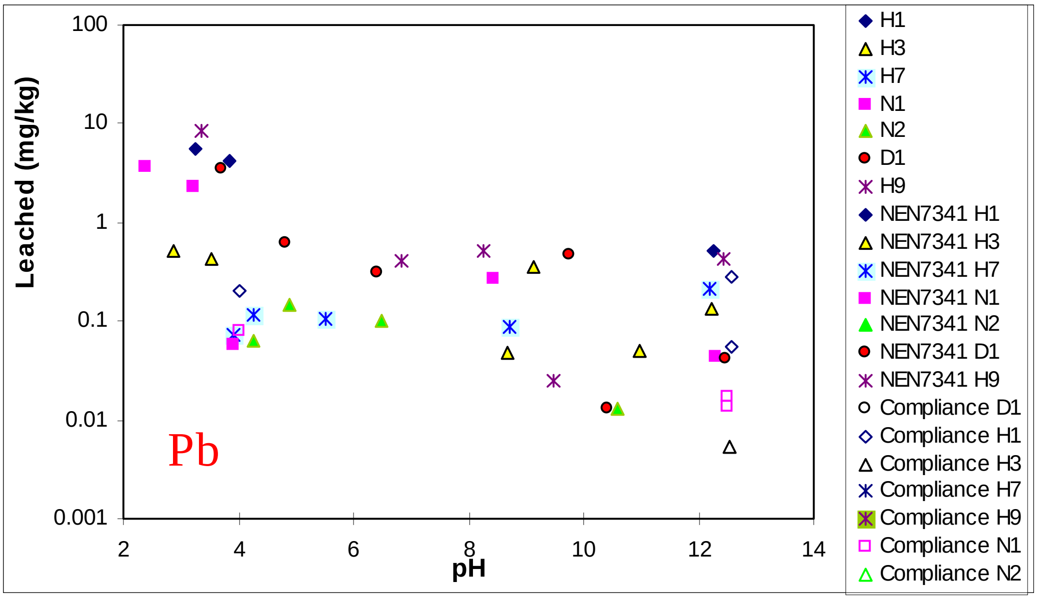

Mo
Leached (mg/kg)
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

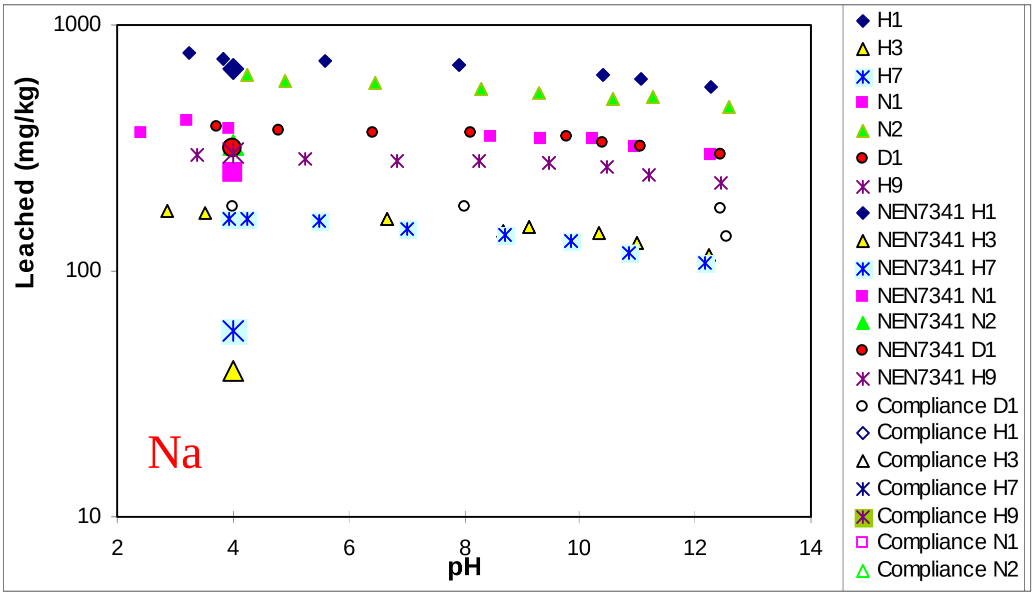

Cd
Leached (mg/kg)
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

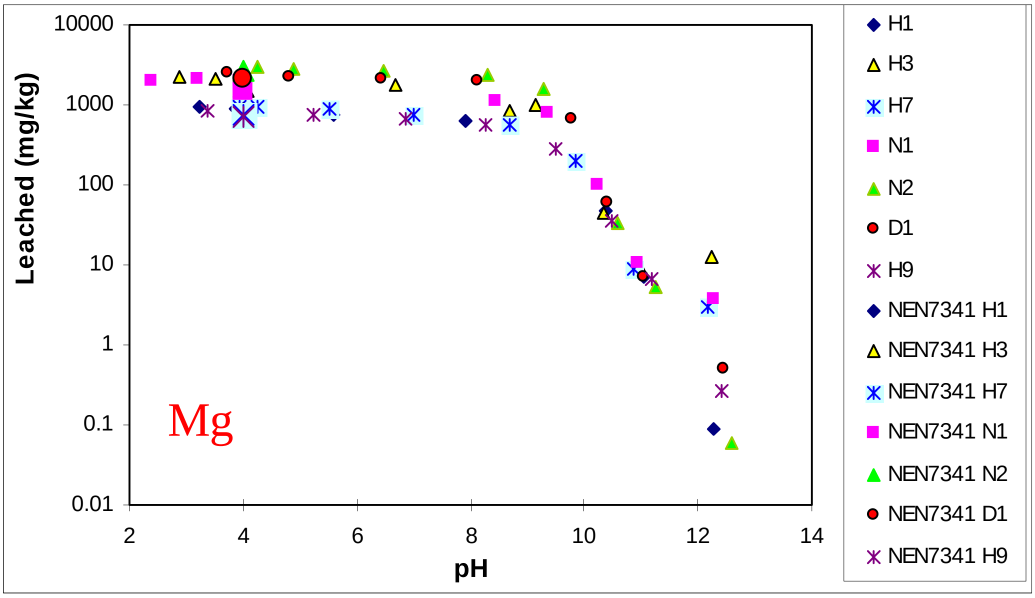

Sn
Leached (mg/kg)
10
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

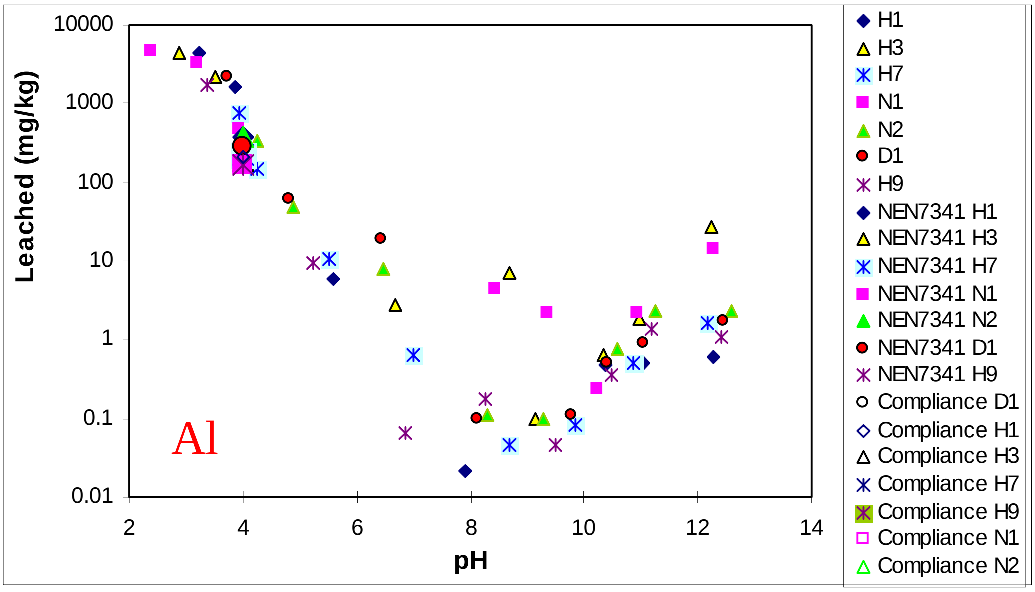

Sb
Leached (mg/kg)
10
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

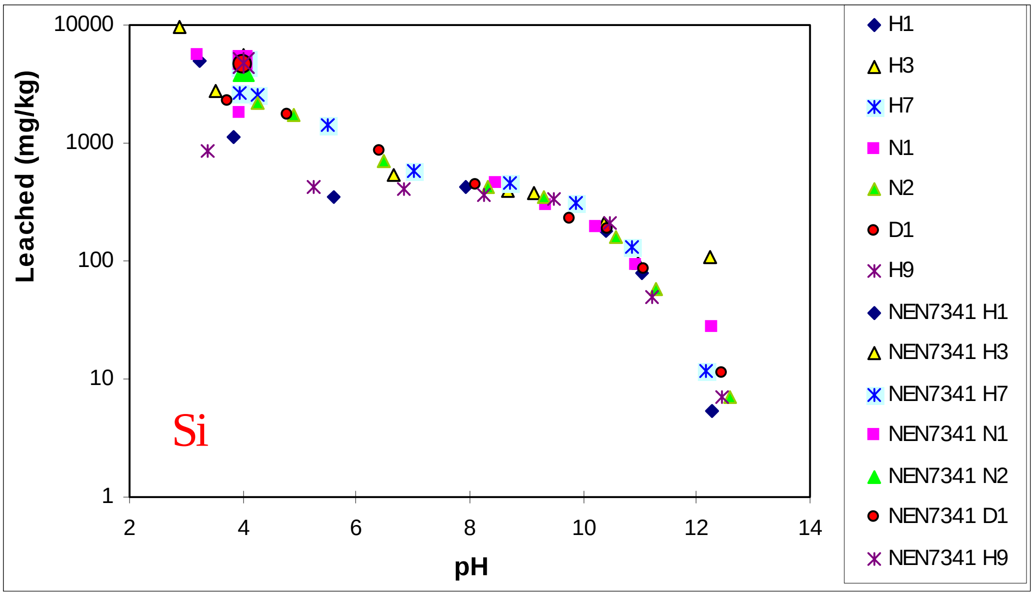

Ba
Leached (mg/kg)
100
10
1
0.1
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

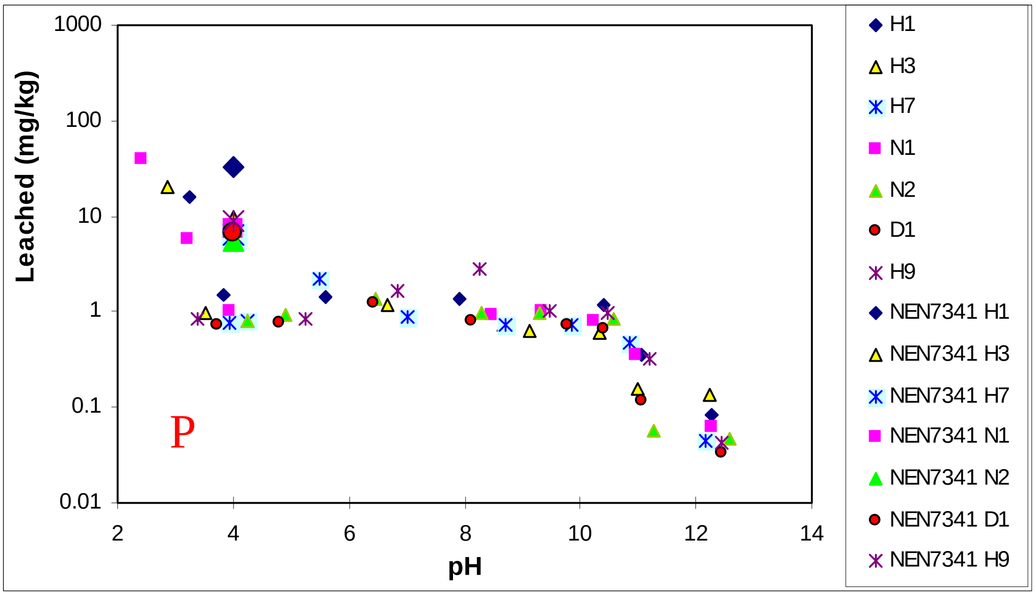

Pb
Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

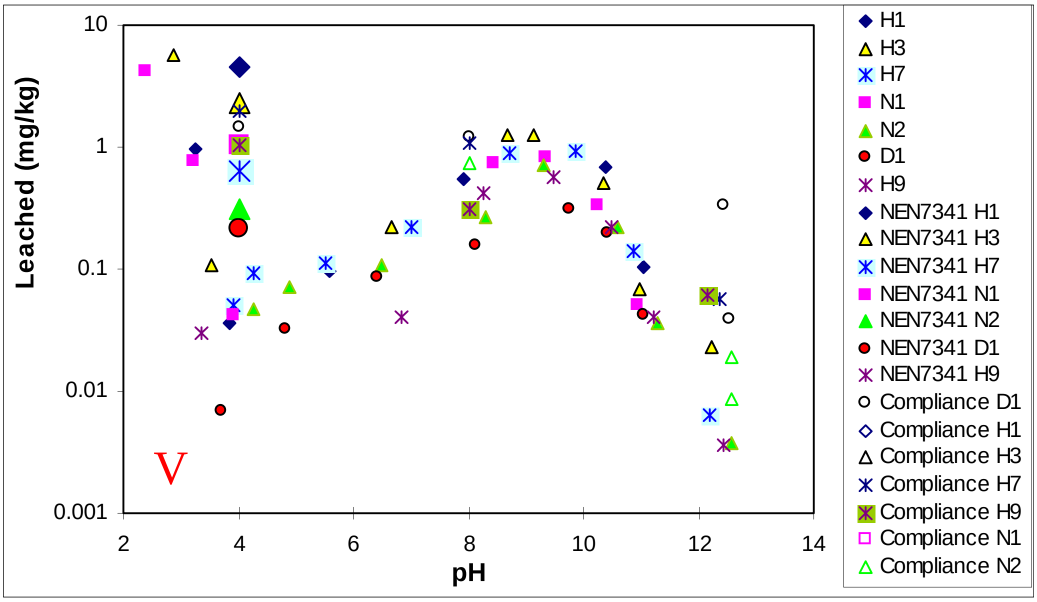

Na
Leached (mg/kg)
1000
100
10
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

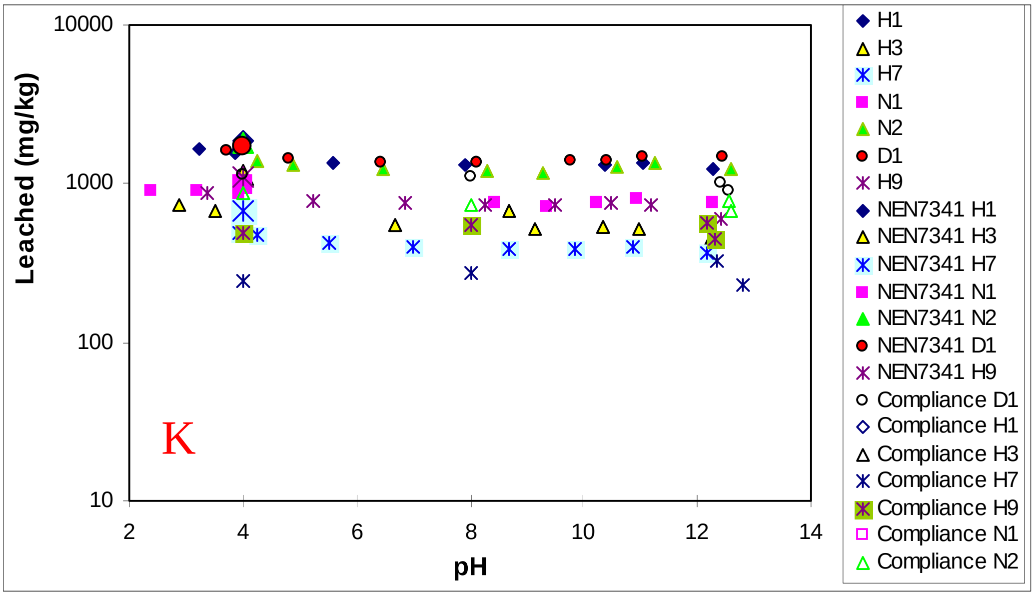

Mg
Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9

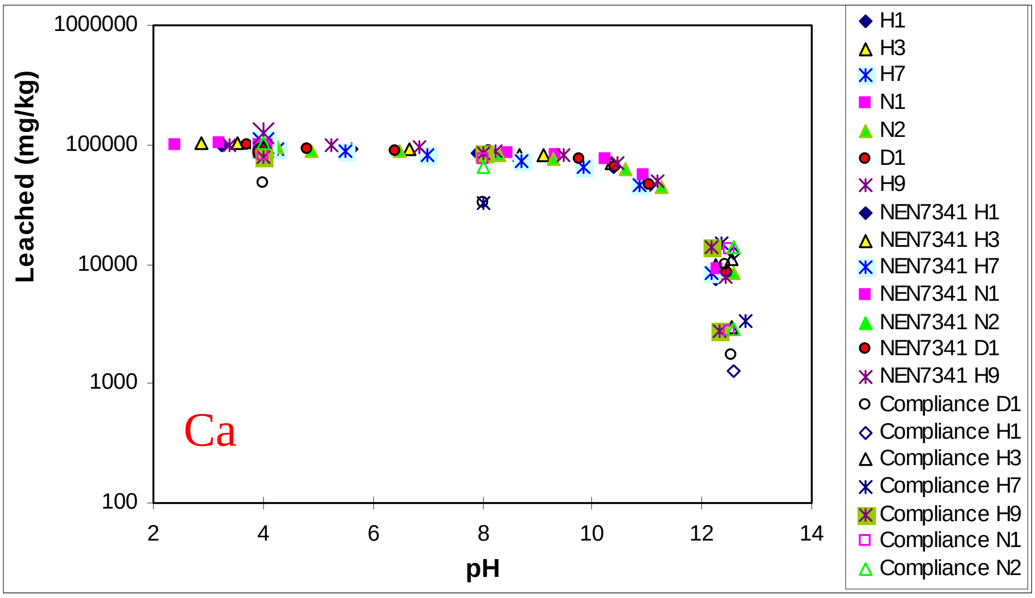

Al
Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

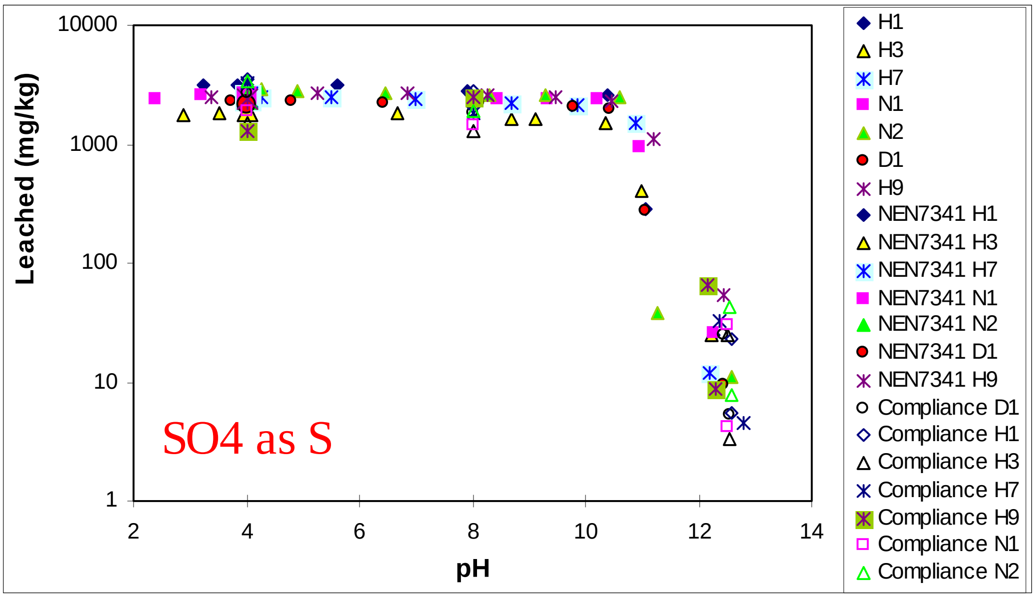

Si
Leached (mg/kg)
pH
10000
1000
100
10
1
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9

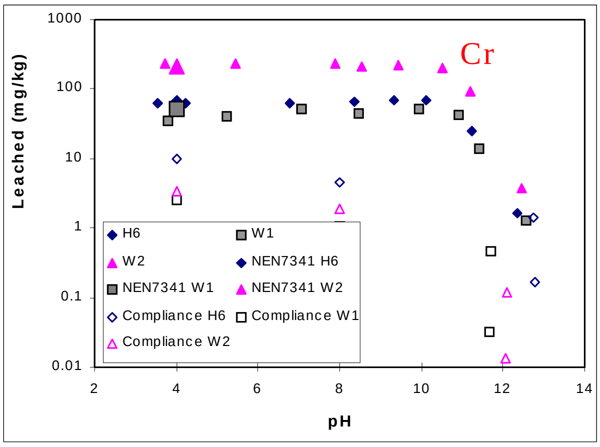

P
Leached (mg/kg)
pH
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9

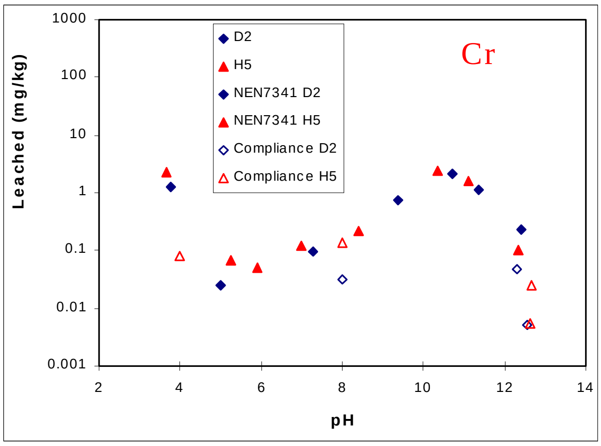

V
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

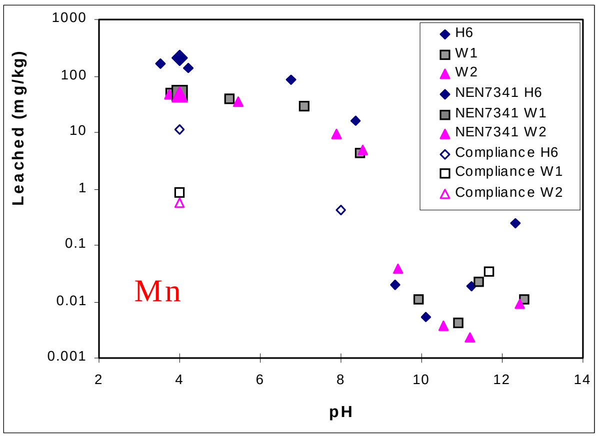

K
Leached (mg/kg)
pH
10000
1000
100
10
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

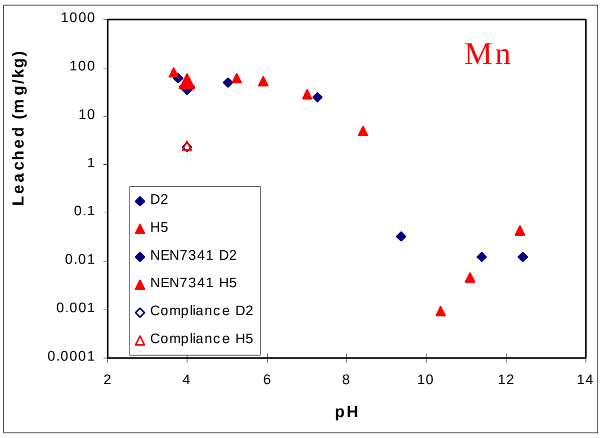

Ca
Leached (mg/kg)
pH
1000000
100000
10000
1000
100
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

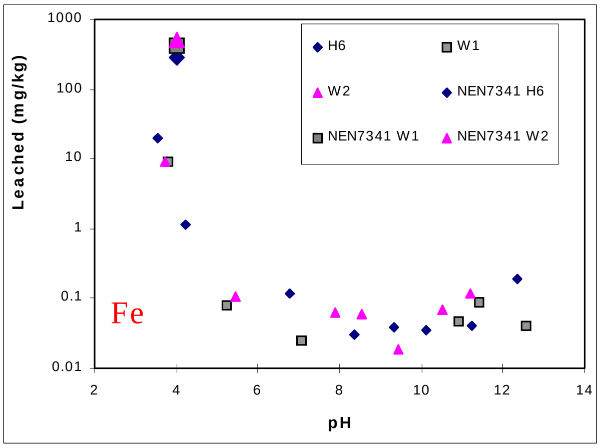

SO4 as S
Leached (mg/kg)
pH
10000
1000
100
10
1
2
4
6
8
10
12
14
H1
H3
H7
N1
N2
D1
H9
NEN7341 H1
NEN7341 H3
NEN7341 H7
NEN7341 N1
NEN7341 N2
NEN7341 D1
NEN7341 H9
Compliance D1
Compliance H1
Compliance H3
Compliance H7
Compliance H9
Compliance N1
Compliance N2

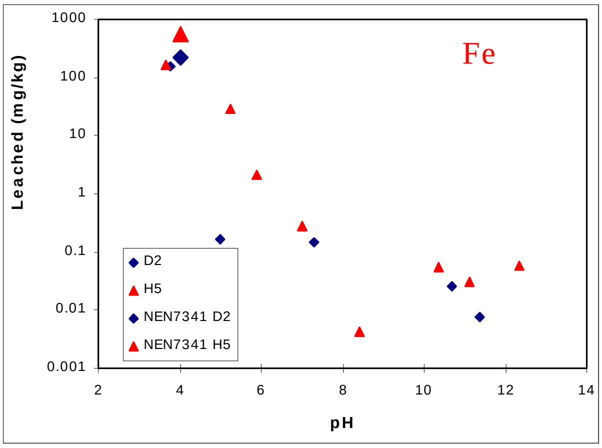

Cr
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

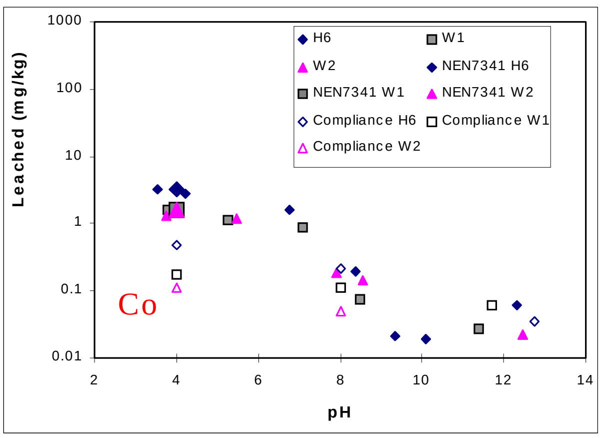

Cr
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

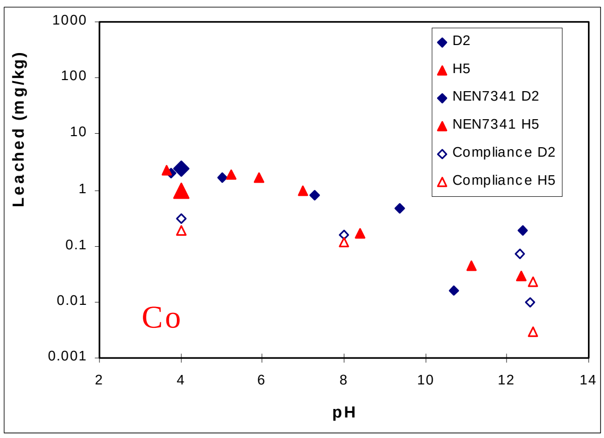

Mn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2


Mn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

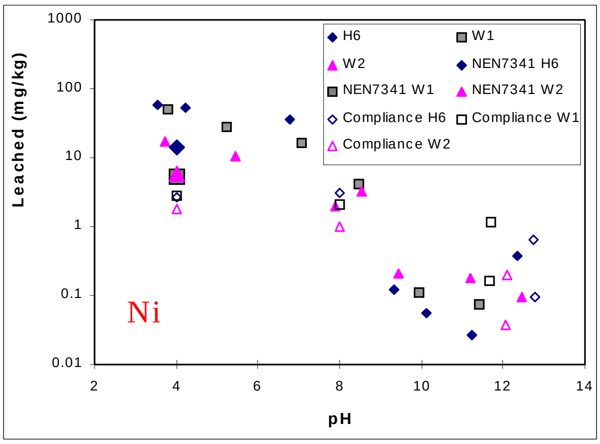

Fe
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2

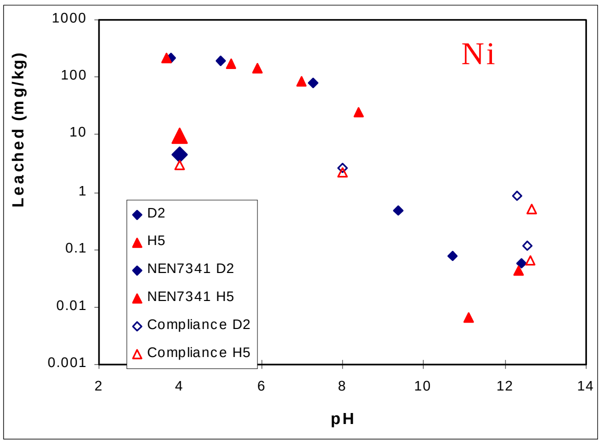

Fe
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5

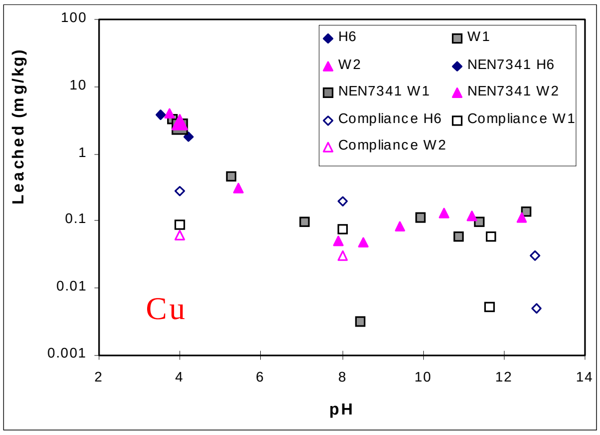

Co
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

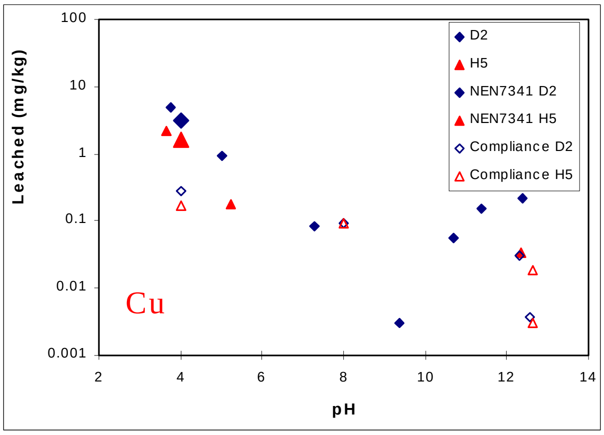

Co
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

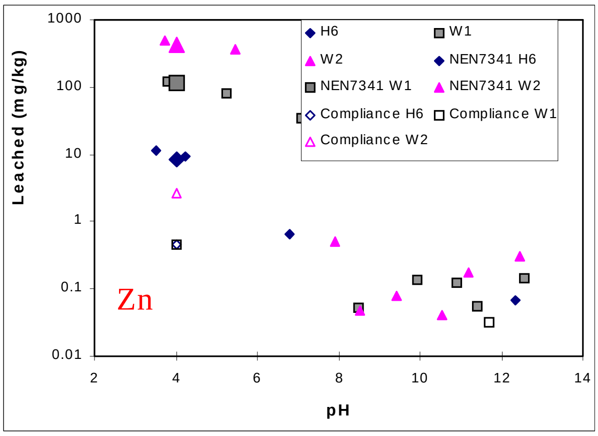
ANNEX 10 Comparison of compliance test data with pH stat test

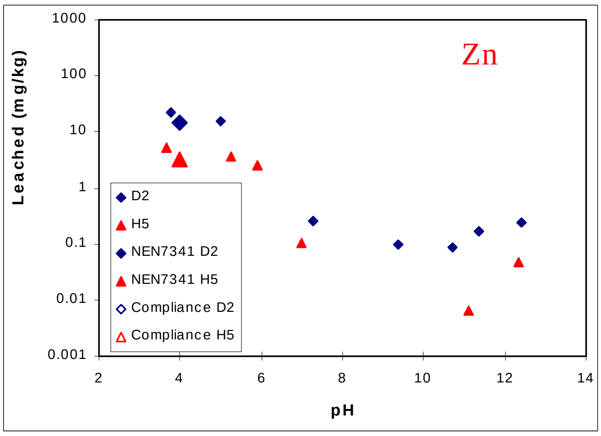


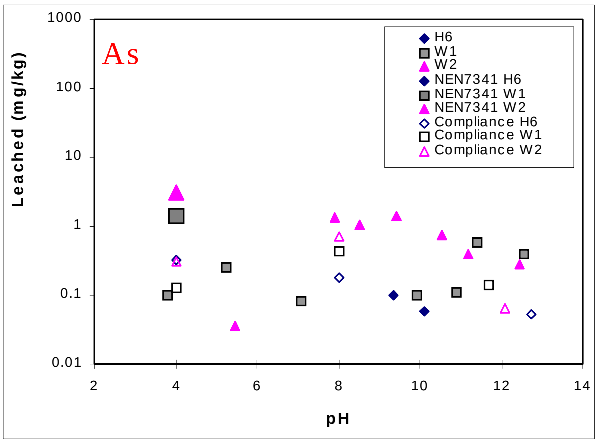


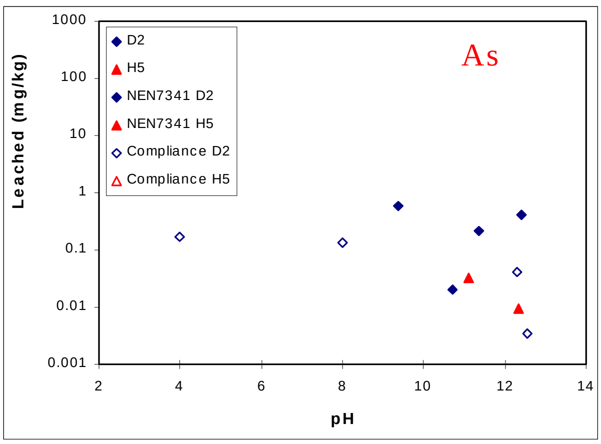


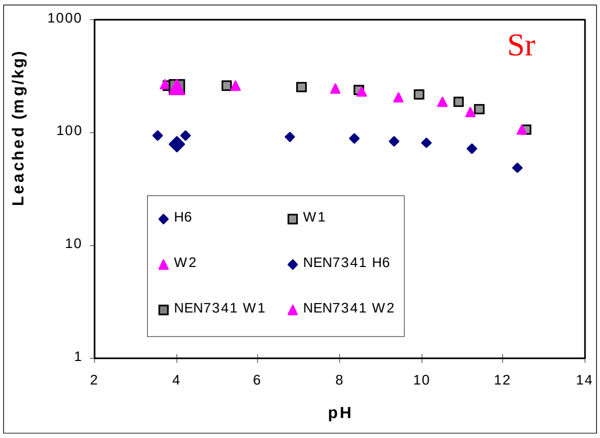


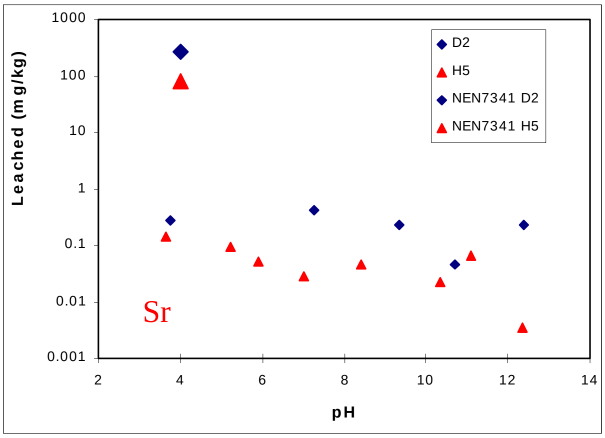


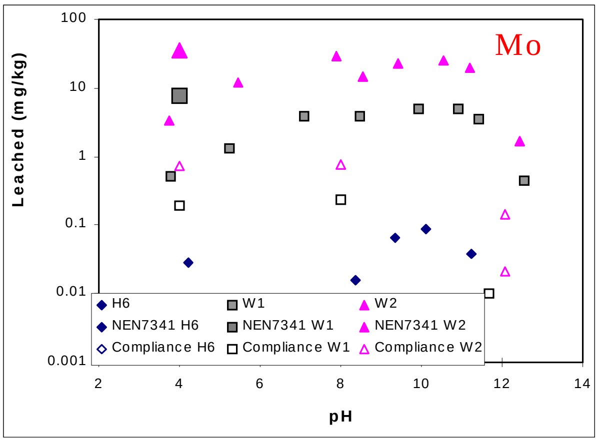


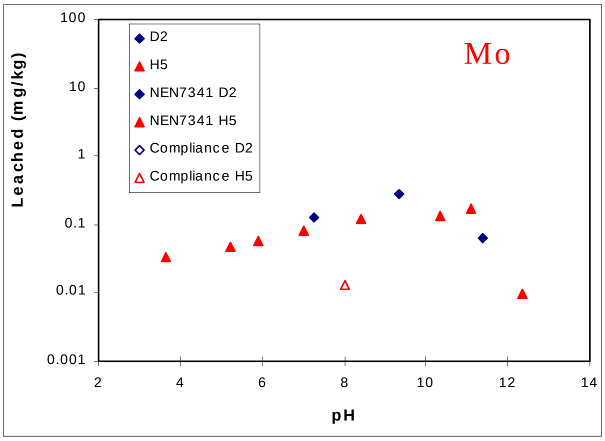


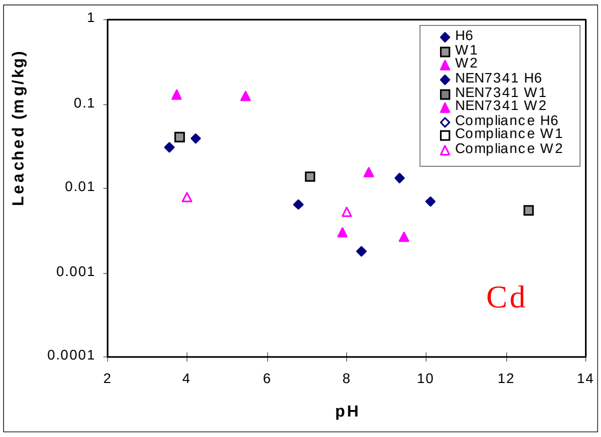


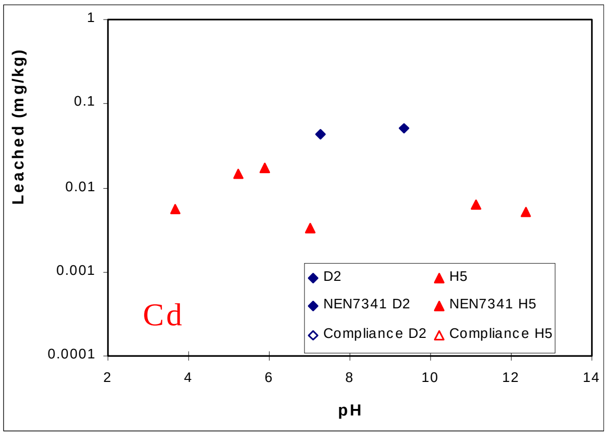

Sr
Leached (mg/kg)
1000
100
10
1
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2

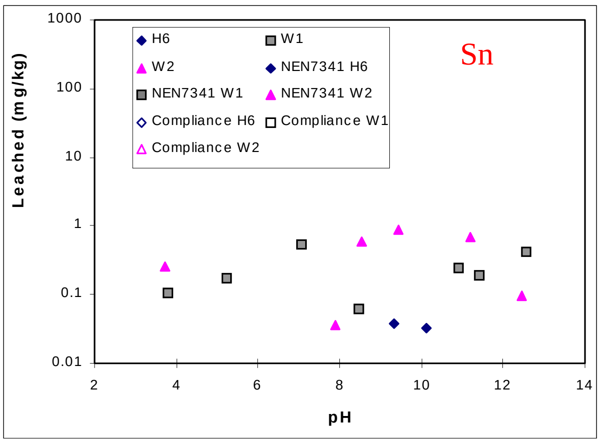

Sr
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5

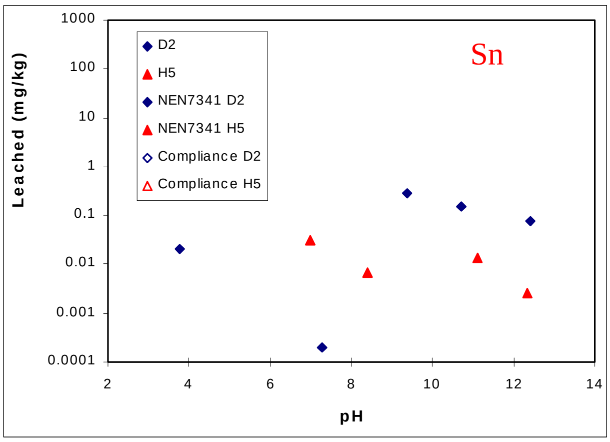

Mo
Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

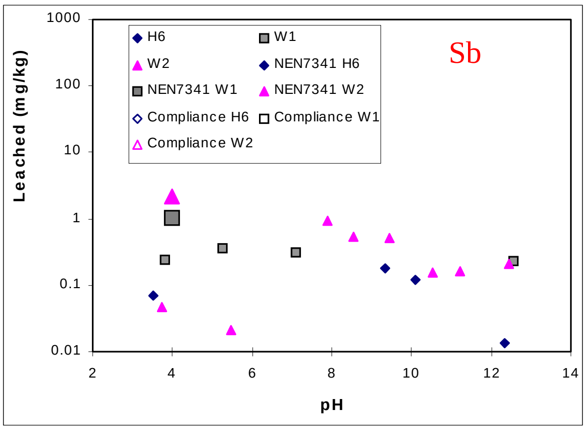

Mo
Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

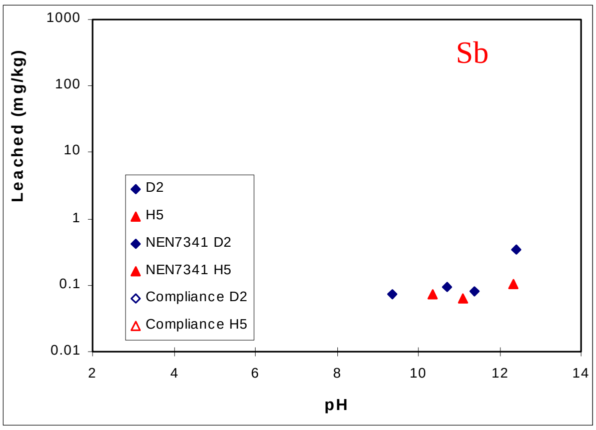

Cd
Leached (mg/kg)
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

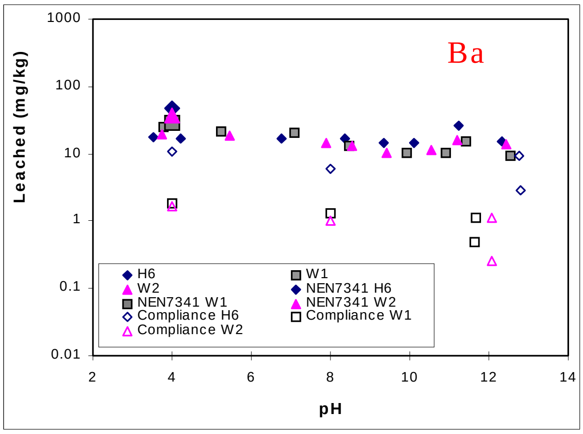

Cd
Leached (mg/kg)
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

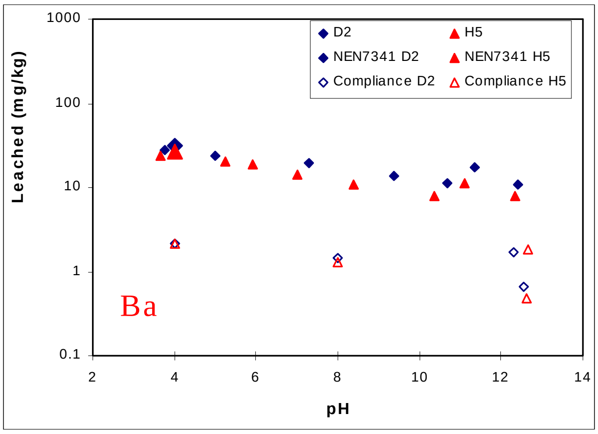

Sn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

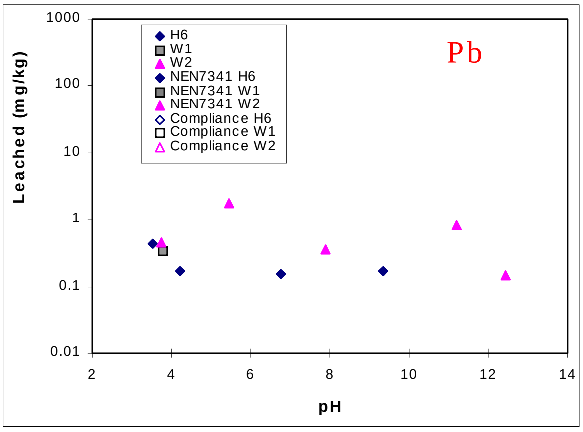

Sn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

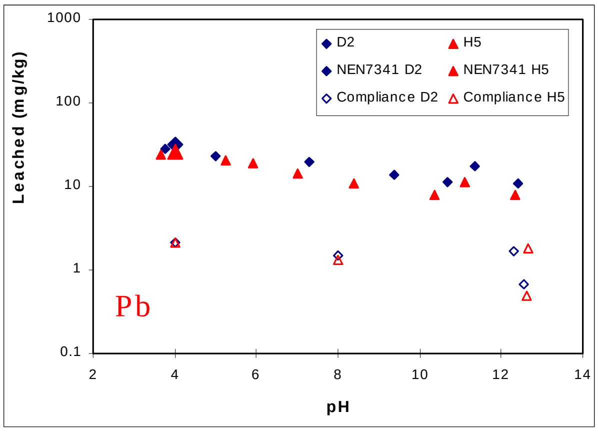

Sb
Leached (mg/kg)
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

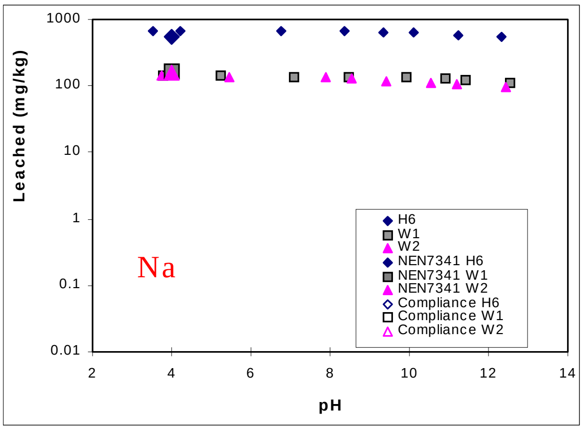

Sb
Leached (mg/kg)
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

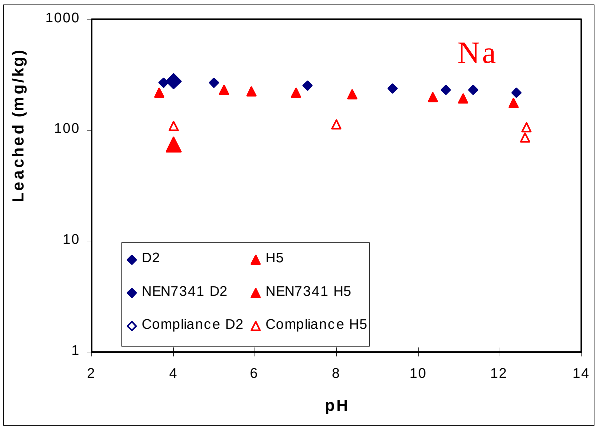

Ba
Leached (mg/kg)
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

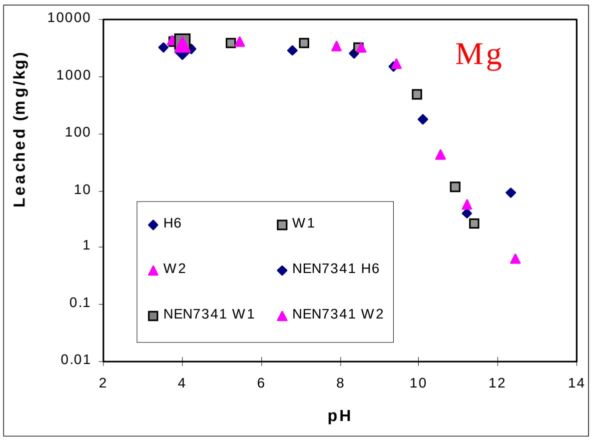

Ba
Leached (mg/kg)
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

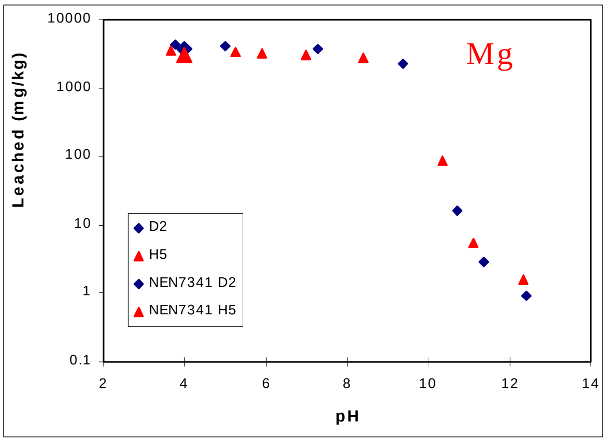

Pb
Leached (mg/kg)
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

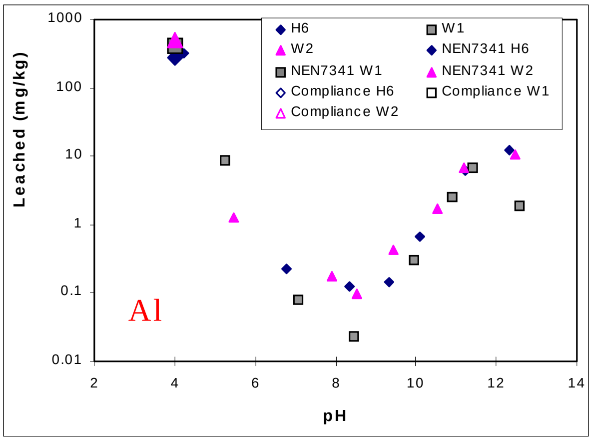

Pb
Leached (mg/kg)
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

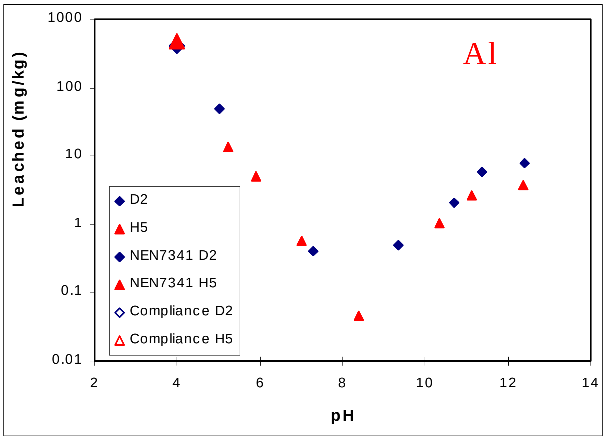

Na
Leached (mg/kg)
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

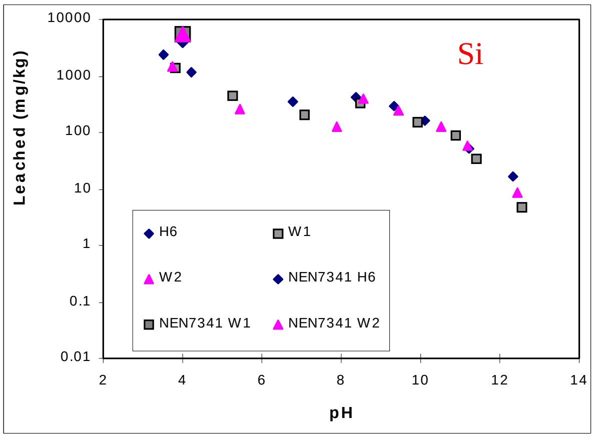

Na
Leached (mg/kg)
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

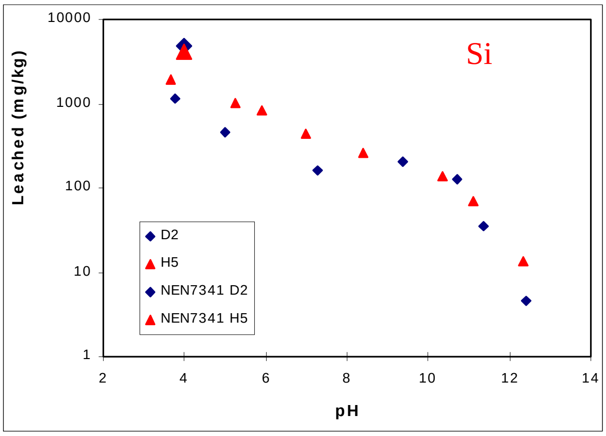

Mg
Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2

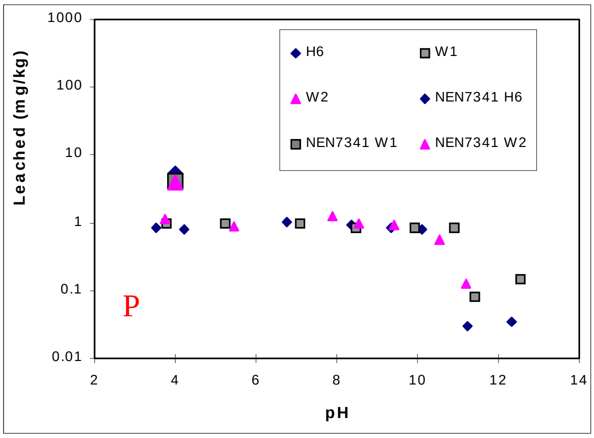

Mg
Leached (mg/kg)
10000
1000
100
10
1
0.1
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5

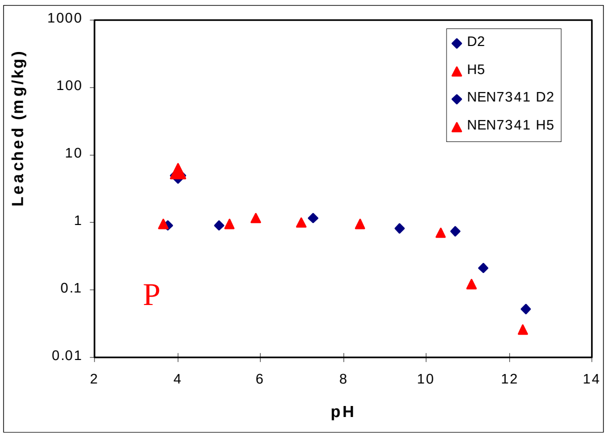

Al
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

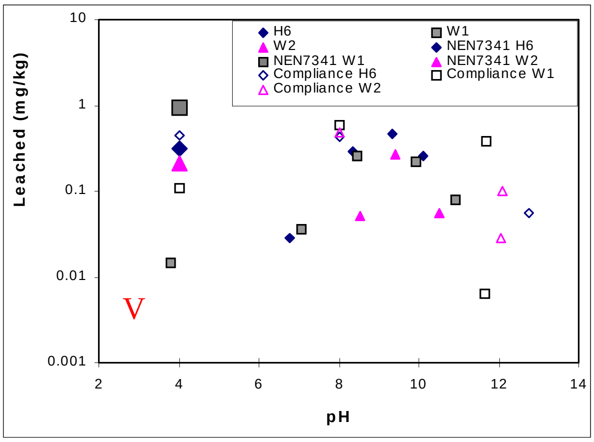

Al
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

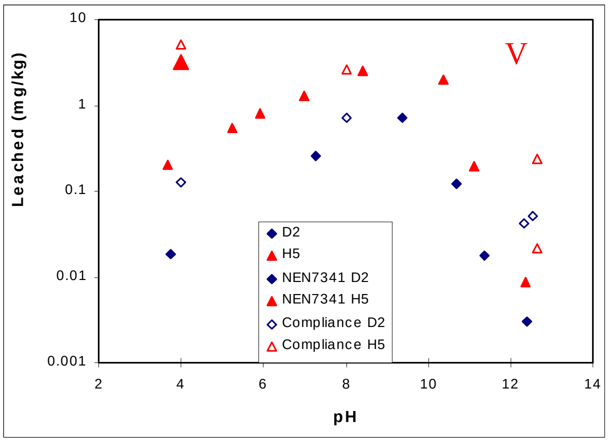

Si
Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2

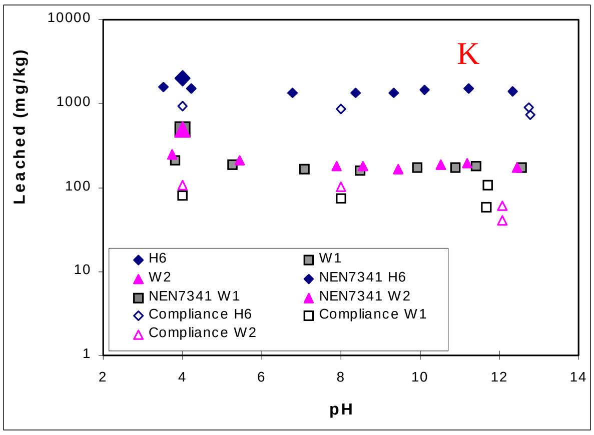

Si
Leached (mg/kg)
10000
1000
100
10
1
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5

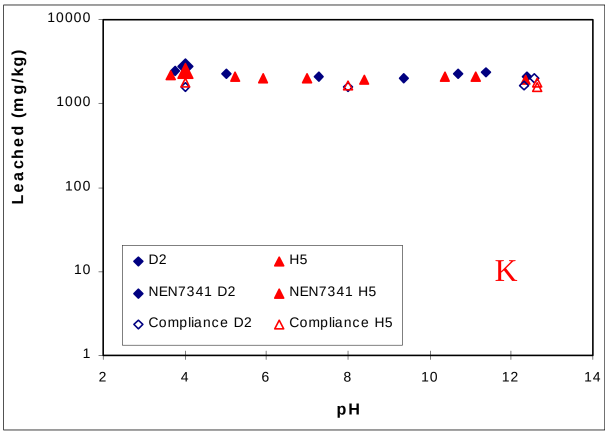

P
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2

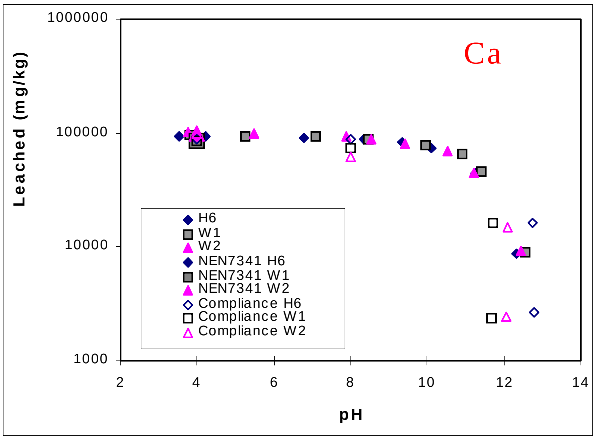

P
Leached (mg/kg)
1000
100
10
1
0.1
0.01
2
4
6
8
10
12
14
pH
D2
H5
NEN7341 D2
NEN7341 H5

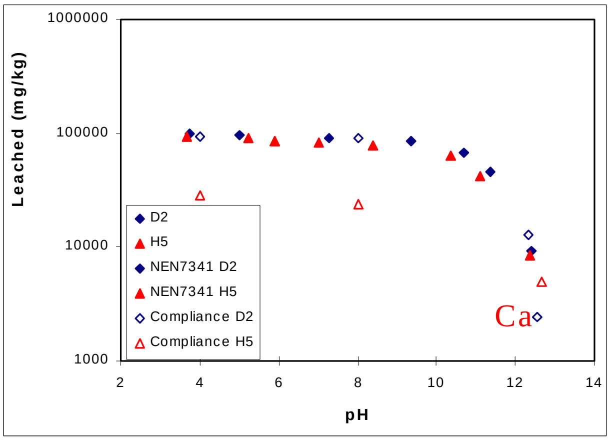

V
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
H6
W2
NEN7341 W1
Compliance H6
Compliance W2
W1
NEN7341 H6
NEN7341 W2
Compliance W1

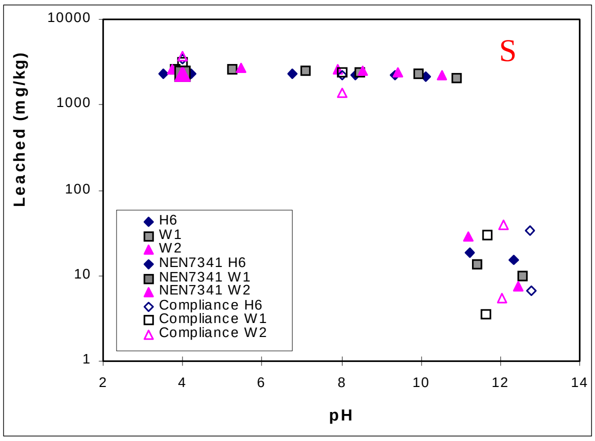

V
Leached (mg/kg)
pH
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

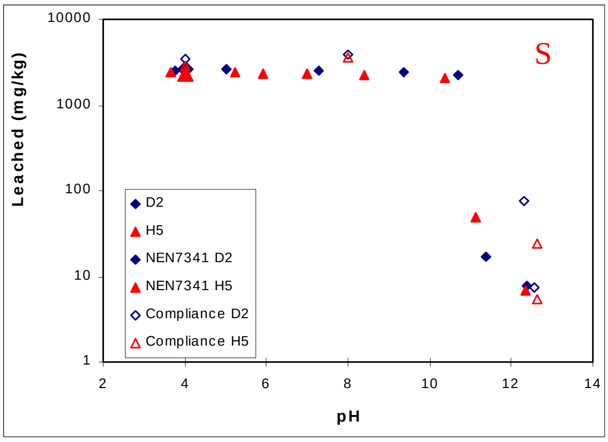

K
Leached (mg/kg)
pH
10000
1000
100
10
1
2
4
6
8
10
12
14
H6
W2
NEN7341 W1
Compliance H6
Compliance W2
W1
NEN7341 H6
NEN7341 W2
Compliance W1


K
Leached (mg/kg)
pH
10000
1000
100
10
1
2
4
6
8
10
12
14
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

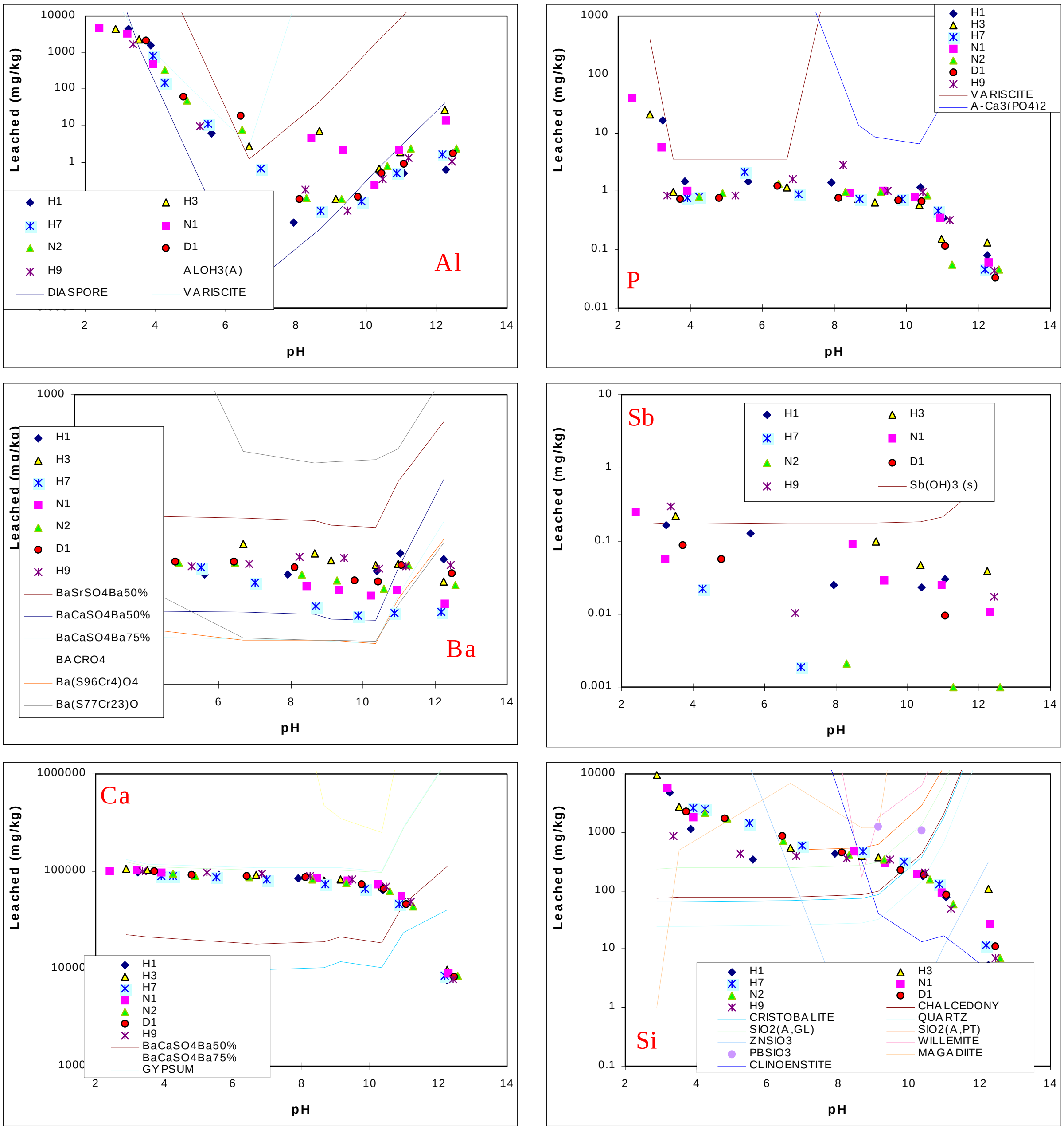

Ca
Leached (mg/kg)
pH
1000000
100000
10000
1000
2
4
6
8
10
12
14
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2


Ca
Leached (mg/kg)
pH
1000000
100000
10000
1000
2
4
6
8
10
12
14
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

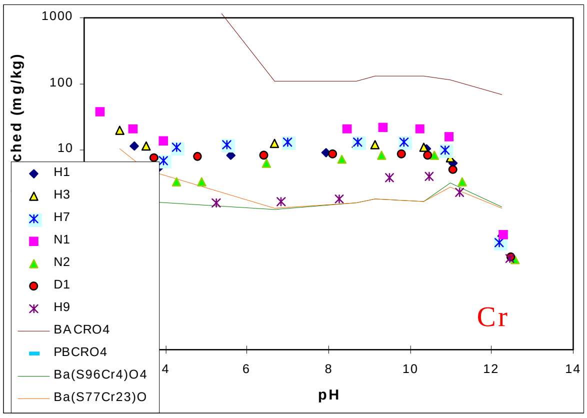

S
Leached (mg/kg)
pH
10000
1000
100
10
1
2
4
6
8
10
12
14
H6
W1
W2
NEN7341 H6
NEN7341 W1
NEN7341 W2
Compliance H6
Compliance W1
Compliance W2

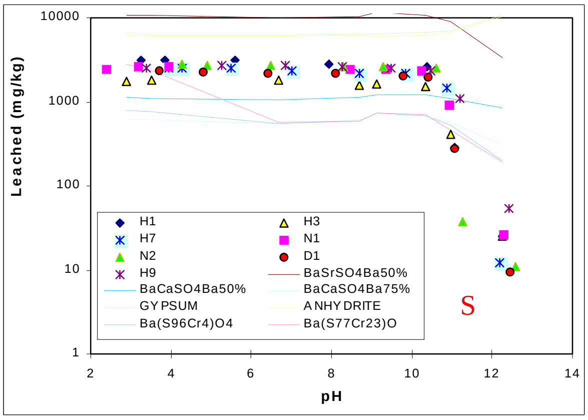

S
Leached (mg/kg)
pH
10000
1000
100
10
1
2
4
6
8
10
12
14
D2
H5
NEN7341 D2
NEN7341 H5
Compliance D2
Compliance H5

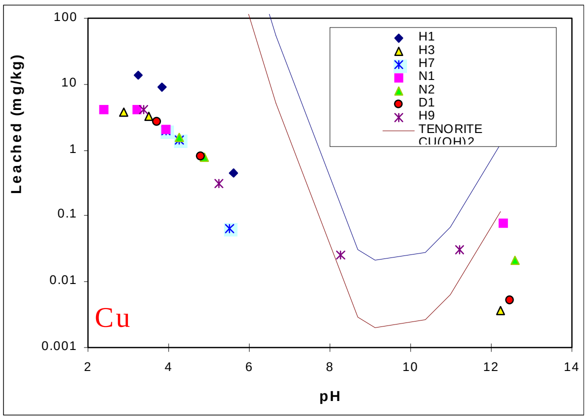
ANNEX 11 Geochemical modelling using ECOSAT – MINTEQA2

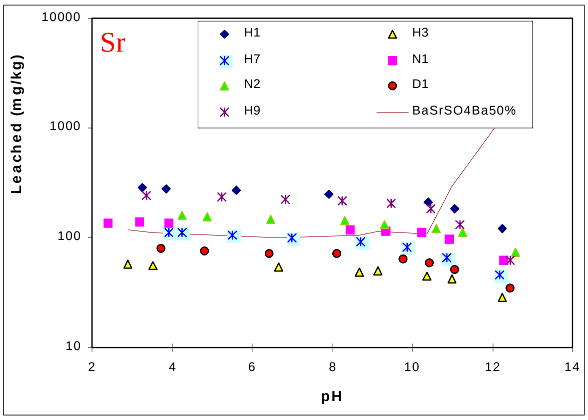


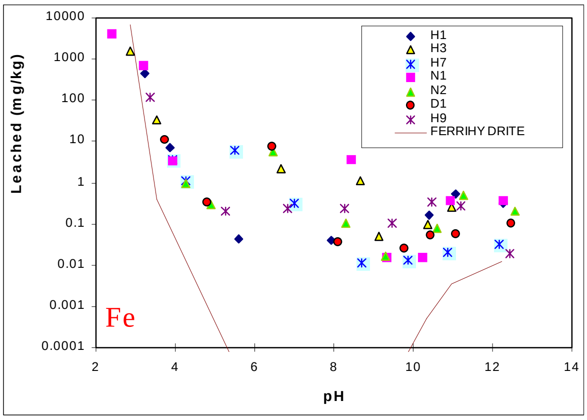
Individual data points reflect pH dependence leaching test data. Calulated solubilities of mineral phases are recalculated from mg/l to mg/kg to allow direct comparison. Drawn lines correspond to specific mineral phases. Deviations of more than an order of magnitude can be ruled out. Example gypsum provides a good match

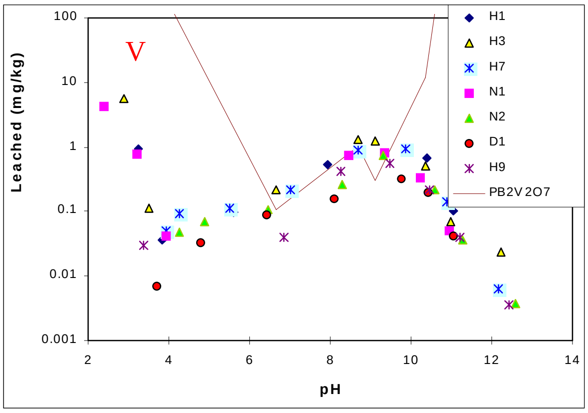

Cr
ched (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
BACRO4
PBCRO4
Ba(S96Cr4)O4
Ba(S77Cr23)O

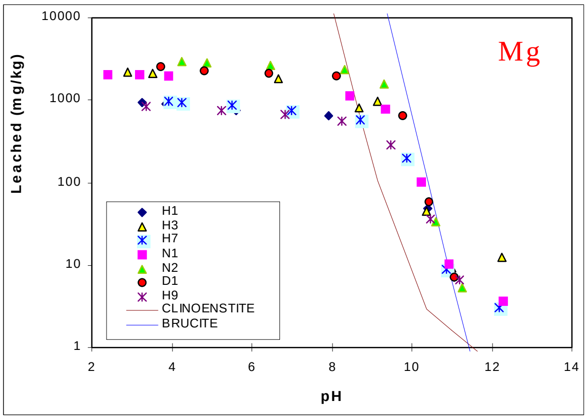

S
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
BaSrSO4Ba50%
BaCaSO4Ba50%
BaCaSO4Ba75%
GYPSUM
ANHYDRITE
Ba(S96Cr4)O4
Ba(S77Cr23)O

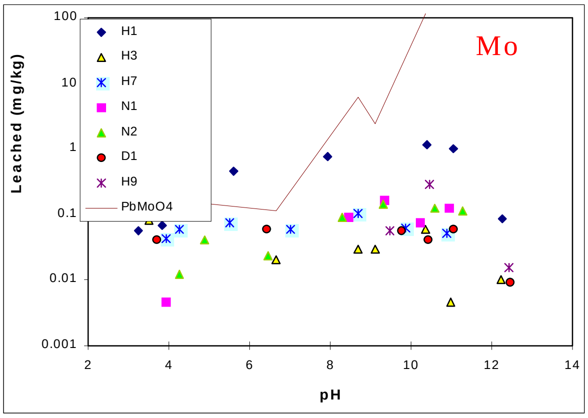

Cu
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
TENORITE
CU(OH)2

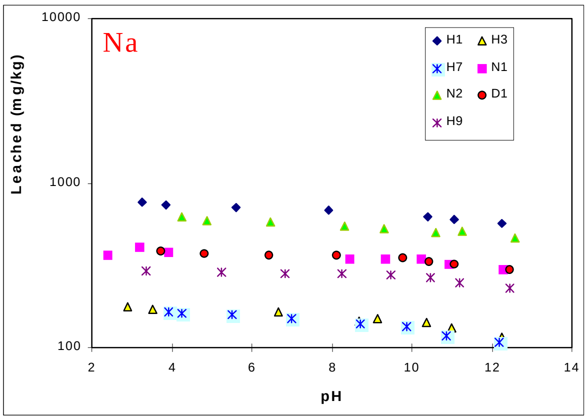

Sr
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
BaSrSO4Ba50%

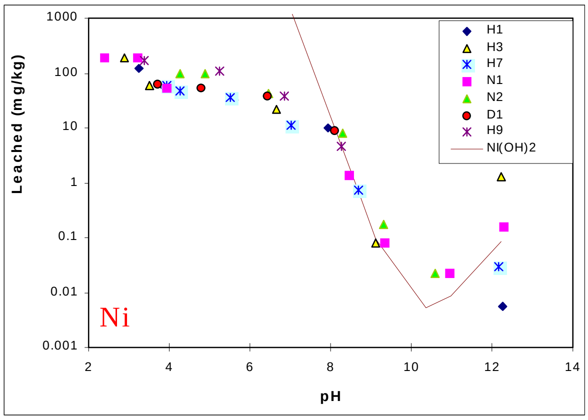

Fe
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
FERRIHYDRITE

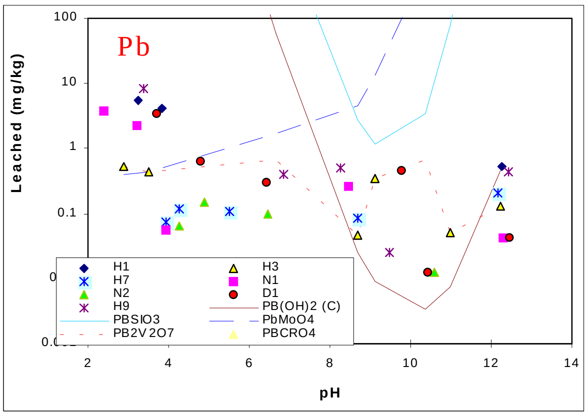

V
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
PB2V2O7

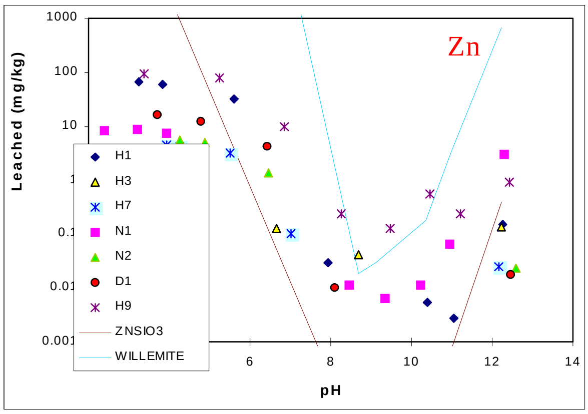

Mg
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
CLINOENSTITE
BRUCITE

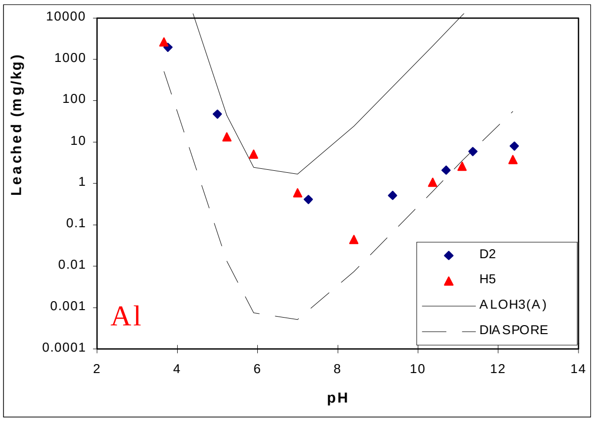

Mo
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
PbMoO4

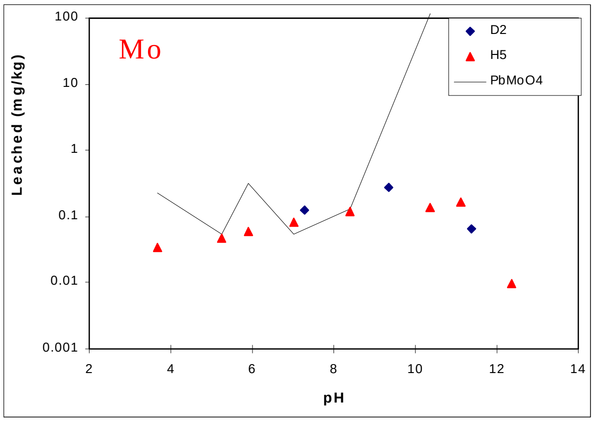

Na
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9

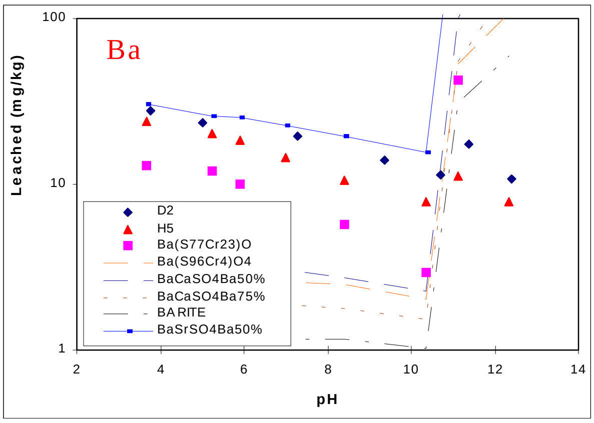

Ni
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
NI(OH)2

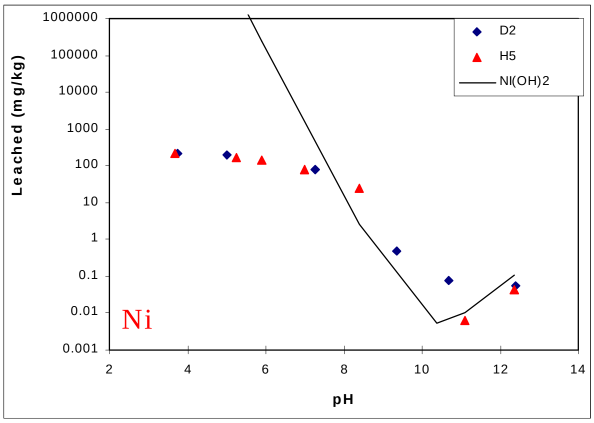

Pb
Leached (mg/kg)
pH
H1
H7
N2
H9
PBSIO3
PB2V2O7
H3
N1
D1
PB(OH)2 (C)
PbMoO4
PBCRO4

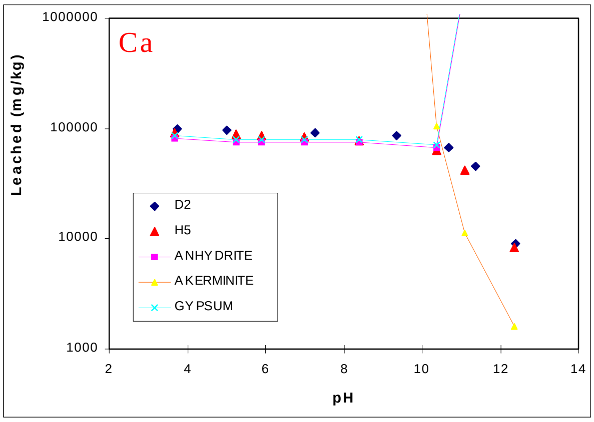

Zn
Leached (mg/kg)
pH
H1
H3
H7
N1
N2
D1
H9
ZNSIO3
WILLEMITE

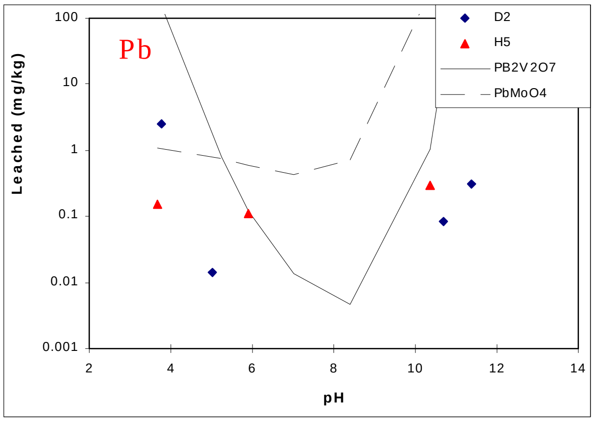

Al
Leached (mg/kg)
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
2
4
6
8
10
12
14
pH
D2
H5
ALOH3(A)
DIASPORE

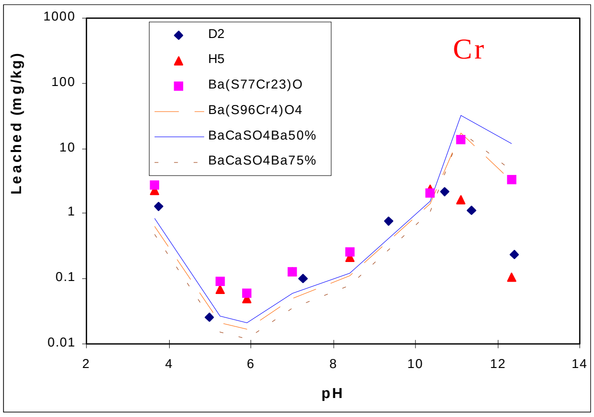

Mo
Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
PbMoO4

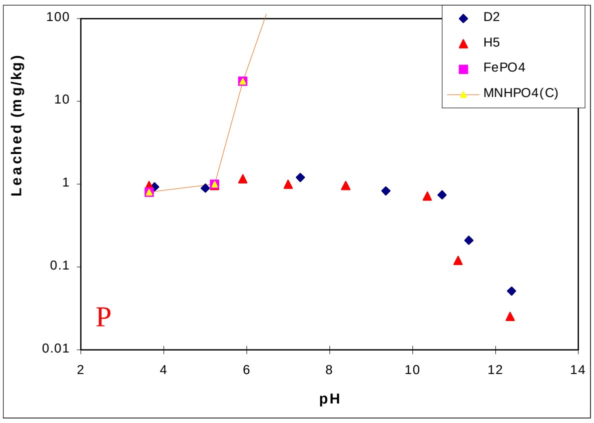

Ba
Leached (mg/kg)
100
10
1
2
4
6
8
10
12
14
pH
D2
H5
Ba(S77Cr23)O
Ba(S96Cr4)O4
BaCaSO4Ba50%
BaCaSO4Ba75%
BARITE
BaSrSO4Ba50%

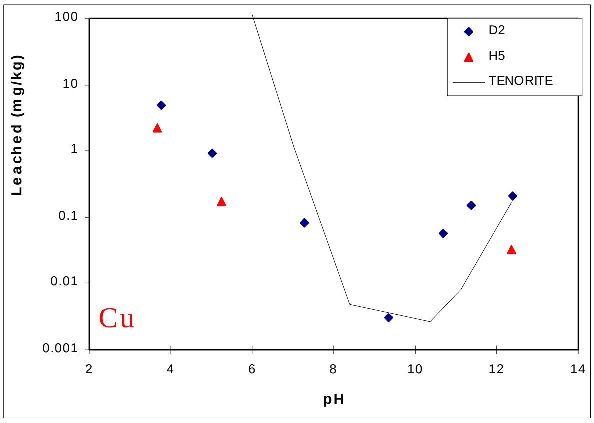

Ni
Leached (mg/kg)
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
NI(OH)2

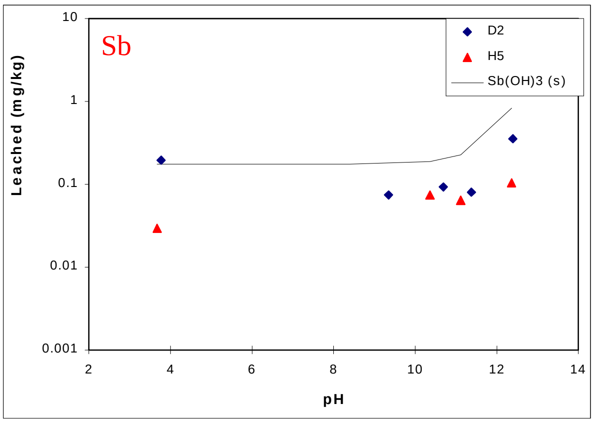

Ca
Leached (mg/kg)
1000000
100000
10000
1000
2
4
6
8
10
12
14
pH
D2
H5
ANHYDRITE
AKERMINITE
GYPSUM

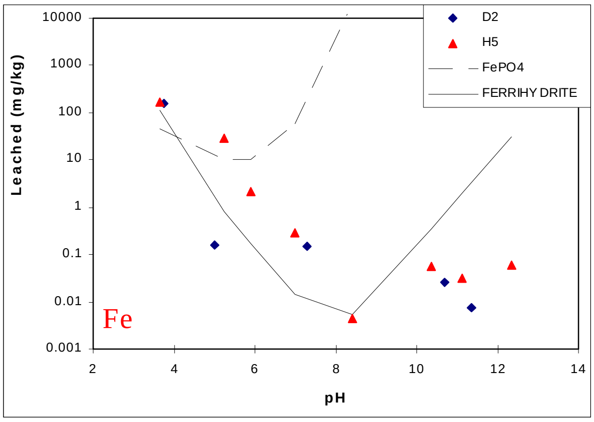

Pb
Leached (mg/kg)
100
10
1
0.1
0.01
0.001
2
4
6
8
10
12
14
pH
D2
H5
PB2V2O7
PbMoO4

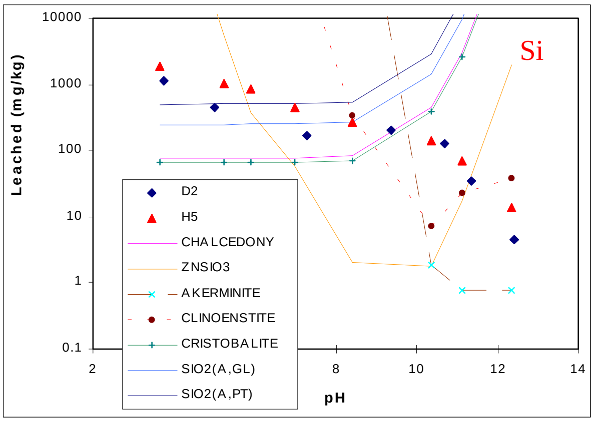

Cr
Leached (mg/kg)
pH
D2
H5
Ba(S77Cr23)O
Ba(S96Cr4)O4
BaCaSO4Ba50%
BaCaSO4Ba75%

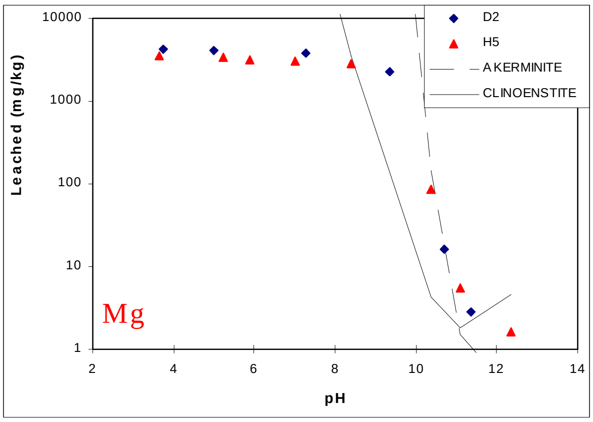

P
Leached (mg/kg)
pH
D2
H5
FePO4
MNHPO4(C)

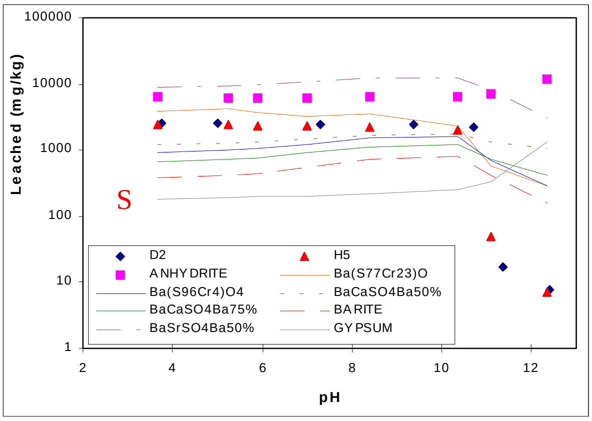

Cu
Leached (mg/kg)
pH
D2
H5
TENORITE

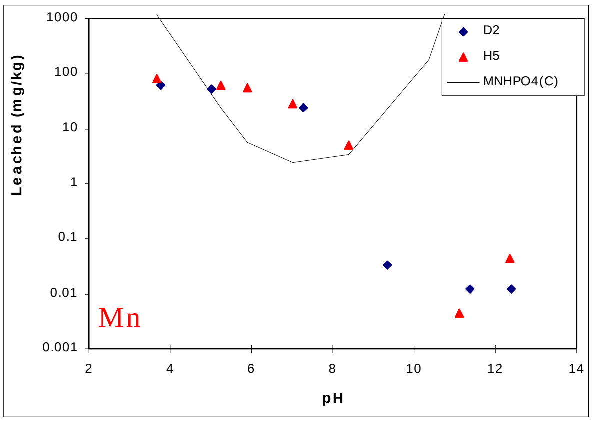

Sb
Leached (mg/kg)
pH
D2
H5
Sb(OH)3 (s)

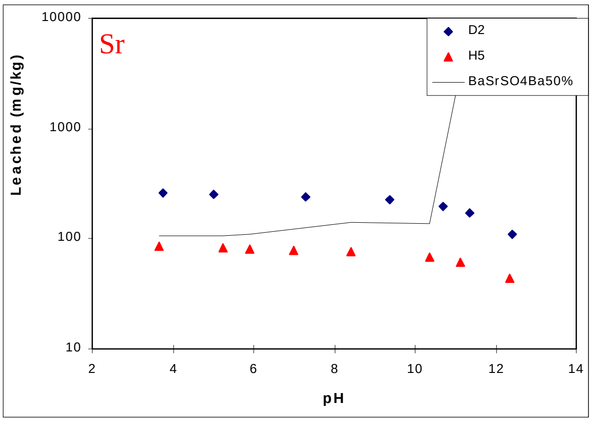

Fe
Leached (mg/kg)
pH
D2
H5
FePO4
FERRIHYDRITE

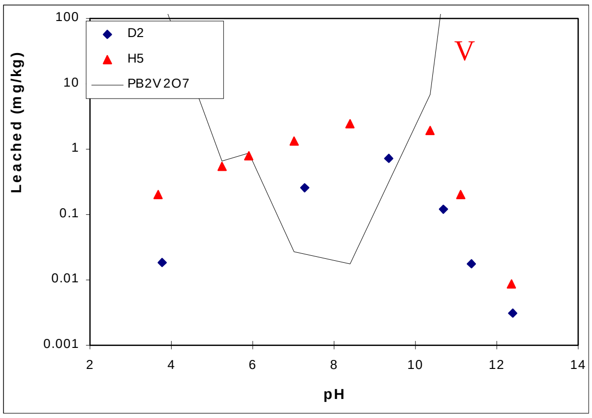

Si
Leached (mg/kg)
pH
D2
H5
CHALCEDONY
ZNSIO3
AKERMINITE
CLINOENSTITE
CRISTOBALITE
SIO2(A,GL)
SIO2(A,PT)

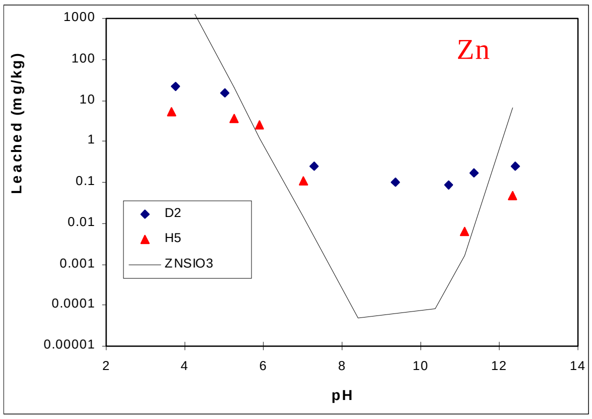

Mg
Leached (mg/kg)
pH
D2
H5
AKERMINITE
CLINOENSTITE

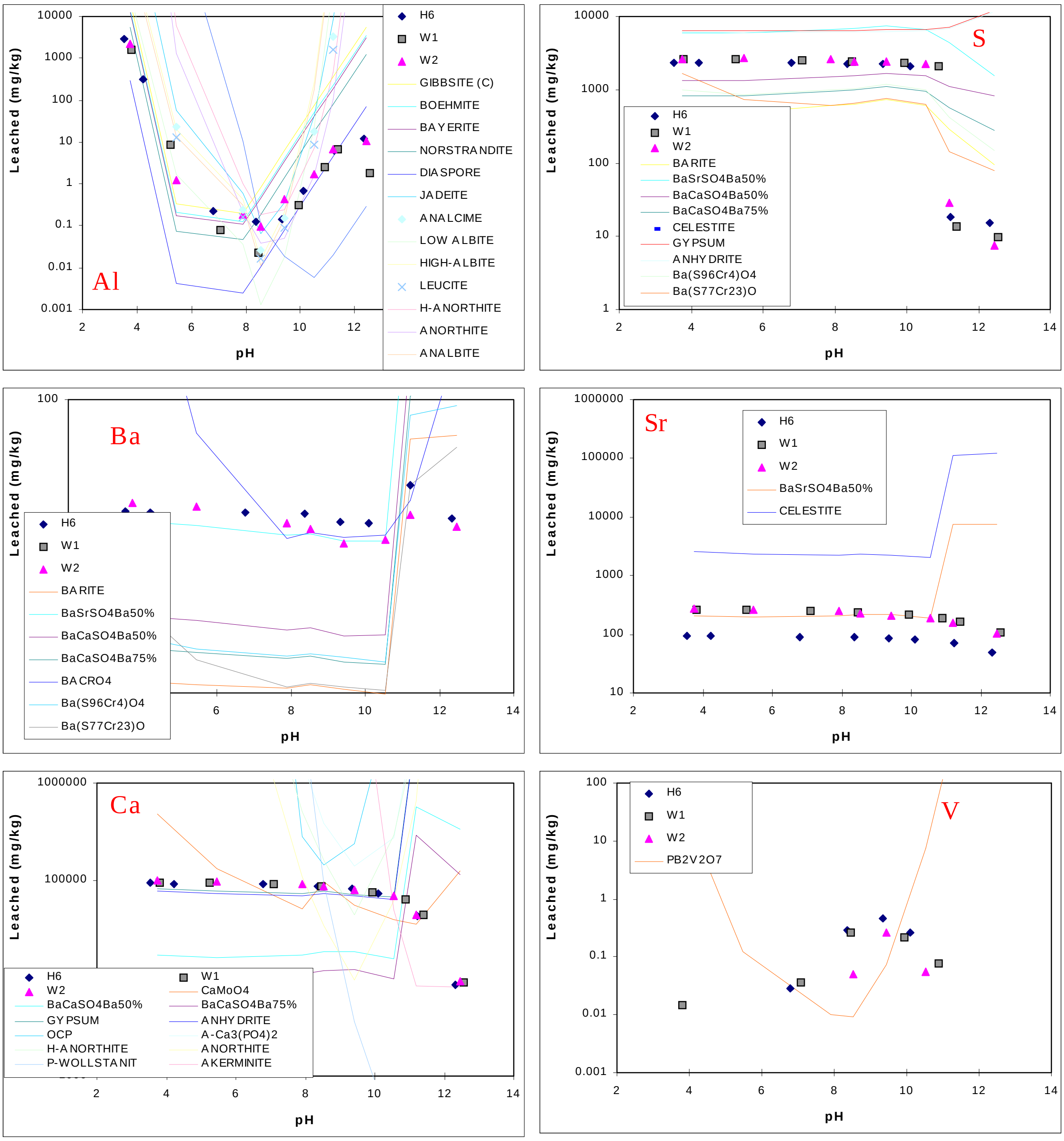

S
Leached (mg/kg)
pH
D2
H5
ANHYDRITE
Ba(S77Cr23)O
Ba(S96Cr4)O4
BaCaSO4Ba50%
BaCaSO4Ba75%
BARITE
BaSrSO4Ba50%
GYPSUM

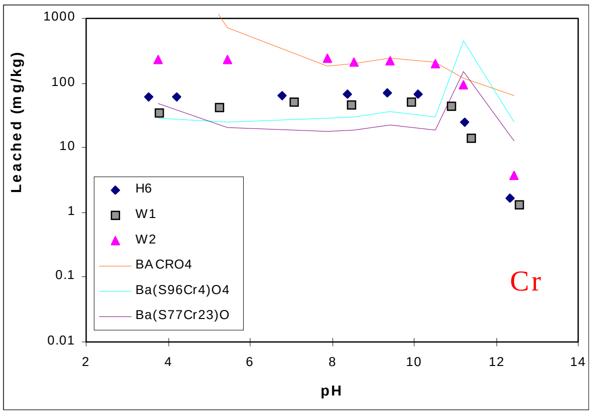

Mn
Leached (mg/kg)
pH
D2
H5
MNHPO4(C)

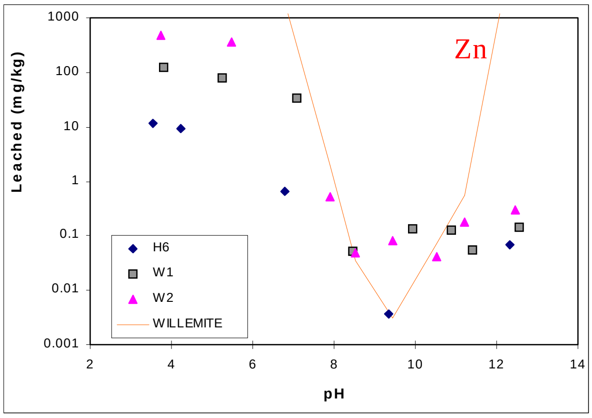

Sr
Leached (mg/kg)
pH
D2
H5
BaSrSO4Ba50%

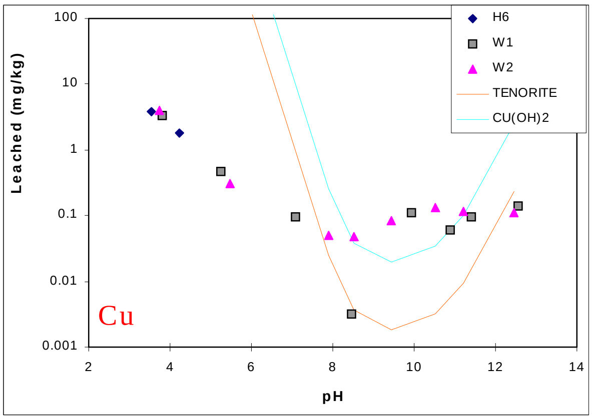

V
Leached (mg/kg)
pH
D2
H5
PB2V2O7

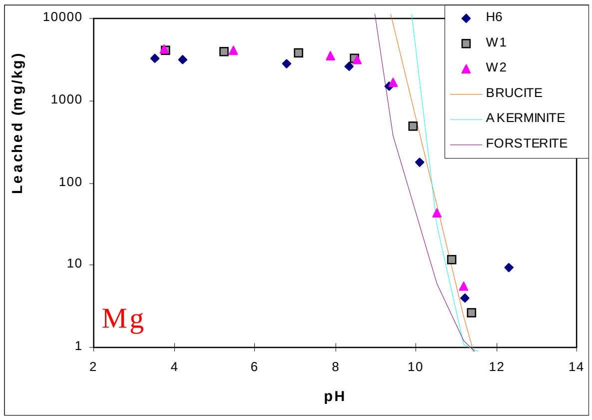

Zn
Leached (mg/kg)
pH
D2
H5
ZNSIO3

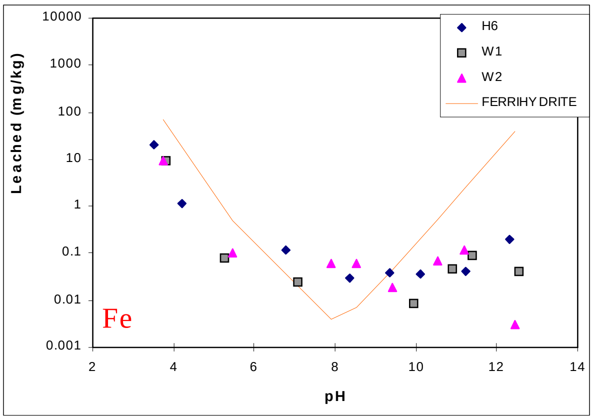

Al
Leached (mg/kg)
pH
H6
W1
W2
GIBBSITE (C)
BOEHMITE
BAYERITE
NORSTRANDITE
DIASPORE
JADEITE
ANALCIME
LOW ALBITE
HIGH-ALBITE
LEUCITE
H-ANORTHITE
ANORTHITE
ANALBITE
S
BARITE
BaSrSO4Ba50%
BaCaSO4Ba50%
BaCaSO4Ba75%
CELESTITE
GYPSUM
ANHYDRITE
Ba(S96Cr4)O4
Ba(S77Cr23)O
Ba
BACRO4
Sr
Ca
CaMoO4
OCP
A-Ca3(PO4)2
P-WOLLSTANIT
AKERMINITE
V
PB2V2O7

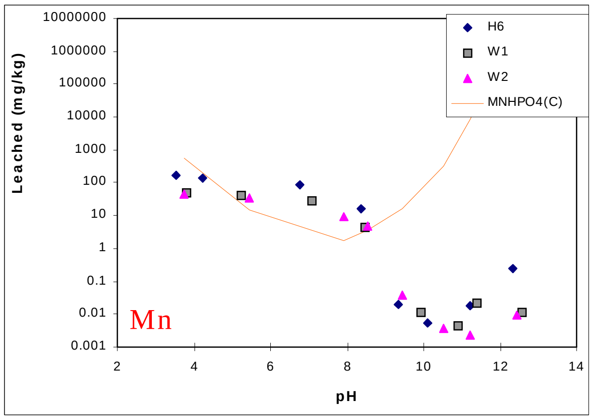

Cr
Leached (mg/kg)
pH
H6
W1
W2
BACRO4
Ba(S96Cr4)O4
Ba(S77Cr23)O
1000
100
10
1
0.1
0.01
2 4 6 8 10 12 14

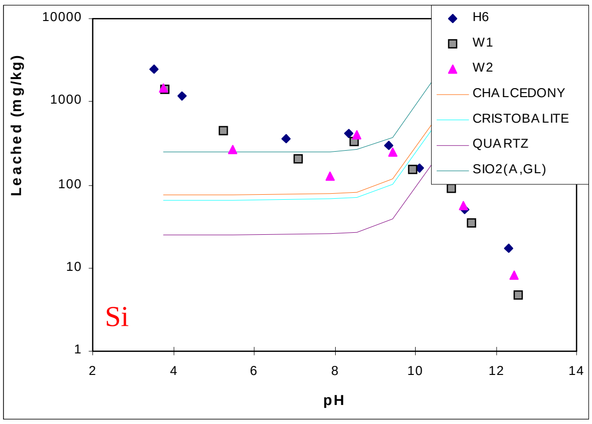

Zn
Leached (mg/kg)
pH
H6
W1
W2
WILLEMITE
1000
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14

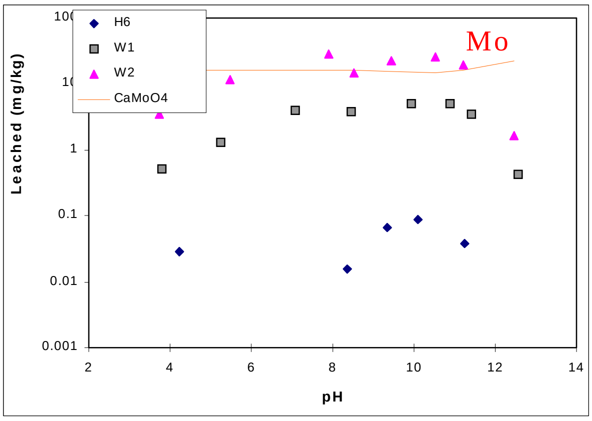

Cu
Leached (mg/kg)
pH
H6
W1
W2
TENORITE
CU(OH)2
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14

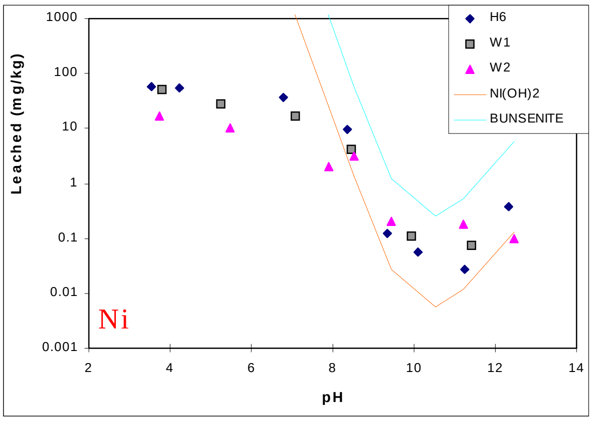

Mg
Leached (mg/kg)
pH
H6
W1
W2
BRUCITE
AKERMINITE
FORSTERITE
10000
1000
100
10
1
2 4 6 8 10 12 14

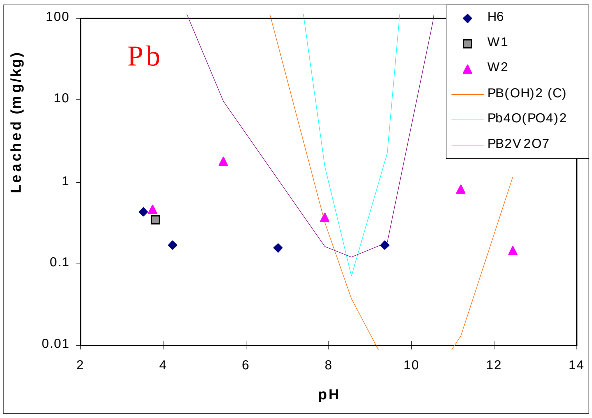

Fe
Leached (mg/kg)
pH
H6
W1
W2
FERRIHYDRITE
10000
1000
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14

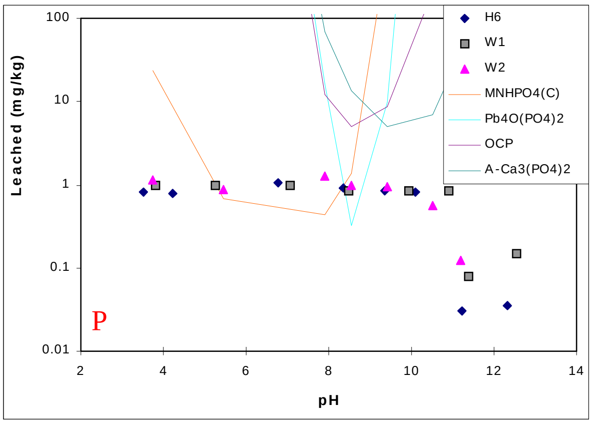

Mn
Leached (mg/kg)
pH
H6
W1
W2
MNHPO4(C)
10000000
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
2 4 6 8 10 12 14

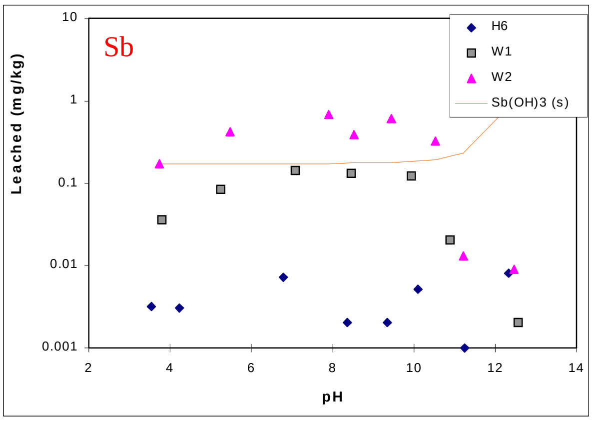

Si
Leached (mg/kg)
pH
H6
W1
W2
CHALCEDONY
CRISTOBALITE
QUARTZ
SIO2(A,GL)


Mo
Leached (mg/kg)
pH
H6
W1
W2
CaMoO4


Ni
Leached (mg/kg)
pH
H6
W1
W2
NI(OH)2
BUNSENITE


Pb
Leached (mg/kg)
pH
H6
W1
W2
PB(OH)2 (C)
Pb4O(PO4)2
PB2V2O7


P
Leached (mg/kg)
pH
H6
W1
W2
MNHPO4(C)
Pb4O(PO4)2
OCP
A-Ca3(PO4)2


Sb
Leached (mg/kg)
pH
H6
W1
W2
Sb(OH)3 (s)

ANNEX 12 Intercomparison of Standard Eluate data for analytical performance.

			EU project Stab. Waste		Dutch Validation		ECN All - 98		NORCEM	VDZ	Obourg	NORCEM	VDZ	Obourg
Method	Element	Unit	Average	Stdev	Average	Stdev	Average	Stdev	Measured			% *	% *	% *
HAAS	As	µg/l					45.0	2.6		25	54		**55**	120
ICP	As	µg/l					159	155						
ICP	Al	mg/l					82.8	3.1		99	93		120	113
ICP	B	mg/l					5.2	0.1						
ICP	Ba	µg/l	523	103	480	130	379	79			165			**44**
ICP	Ca	mg/l	2330	129	2231	234	2252	56		4099	3230		**182**	**143**
ICP	Cd	mg/l	8.63	0.58	8.5	0.6	8.0	0.3	8.6	8.2	7.5	108	103	94
ICP	Co	µg/l					149	23		115	129		77	87
ICP	Cr	µg/l					324	13	400	219	296	124	**68**	91
ICP	Cu	mg/l			5.3	0.7	5.4	0.2	5.8	5.3	4.6	108	99	85
ICP	Fe	µg/l					251	16						
ICP	K	mg/l	937	15.2	933	23	975	44		622	871		**64**	89
ICP	Li	µg/l			930	240	710	70						
ICP	Mg	mg/l			129	10	131	2.1			134			102
ICP	Mn	mg/l					2.7	0.1	3.2	2.7	2.5	119	102	92
ICP	Mo	µg/l			60	10	70	30	130	47	50	**186**	67	71
ICP	Na	mg/l	569	30	567	29	586	24		589	489		101	83
ICP	Ni	mg/l			0.33	0.02	0.26	0.01	0.51	0.30	0.22	**195**	114	84
ICP	P	µg/l					646	72						
ICP	Pb	µg/l	2.8	0.7	2670	610	2586	122	3040	3450	2553	118	**133**	99
ICP	S	mg/l	532	24	523	40	542	27						
ICP	Sb	µg/l					54	42		66.90			123	
ICP	Se	µg/l					45	69						
HAAS	Se	µg/l					80	0.2						
ICP	Sn	µg/l					2.2	3.2		1.43			65	
ICP	Si	mg/l			153	21	178	13			185			104
ICP	Sr	mg/l	8.04	0.42	7.9	0.7	7.4	0.2						
ICP	Ti	µg/l					4.0	8.1						
ICP	V	µg/l					65	4	125	50	54	**192**	78	83
ICP	Zn	mg/l	290	13	296	23	279	10	291	318	361	104	114	**130**
ICP	Hg	µg/l							0.50	0.71				
ICP	Be	µg/l								14	15			
ICP	Tl	µg/l								59				

* Percent expressed relative to values based on 98 measurements. Values exceeding 25 % above or below this value are given in bold. Between lab variability of 25% common.

ANNEX 13 Interlaboratory comparison of the monolith leach test

Interlaboratory comparison of the monolith leach test

Code	Date	Reference time(days)	Al mg/m2	As mg/m2	Ba mg/m2	Ca mg/m2	Cd mg/m2	Cr mg/m2	Cu mg/m2	K mg/m2
N	1999	32	419	0.73	4.50			5.86	0.73	24840
V1	1999	32			2.47	15103	0.02	5.09		25838
V2	1999	32			2.90	12578	0.02	4.14		25906
O1	1999	32			0.99	9776		5.52		25921
O2	1999	32			0.56	8531	0.12	7.64		28416
O3	1999	32			0.81	10194	0.21	6.89		27433
E	1999	32	756	1.63	2.66	8205	0.25	5.49	3.28	25804
Average			587	1.2	2.1	10731	0.1	5.8	2.0	26308
St dev			239	0.6	1.4	2644	0.1	1.2	1.8	1201
Var *			**41**	**54**	**67**	25	**83**	20	**90**	4.6
European intercomparison study 1994					Ba	Ca				
Average	1994				2.3	12585				

SR %(Between laboratory variability) ca. 25 %

	Mo mg/m2	Na mg/m2	Pb mg/m2	Sb mg/m2	Sn mg/m2	Sr mg/m2	V mg/m2	Zn mg/m2	SO4 mg/m2	Cl mg/m2
N	0.76	16593	0.65	2.17	0.87		6.80	1.79	5693	30090
V1	0.41	10949	0.25		0.25	28.5		0.35	4920	18031
V2	0.40	11560	0.25		0.25	28.4		0.25	4795	17951
O1	1.45	15833	0.63			35.5	3.57	0.46	4447	19559
O2	1.41	18360	0.23			20.4	5.05	0.46	7928	20789
O3	1.35	17482	0.58			29.7	3.99	0.45	6387	21006
E	0.42	17805	2.62	2.12	0.99	29.9	5.54	17.7	5006	
Average	0.89	15512	0.74	2.15	0.59	28.75	4.99	3.06	5597	21238
St dev	0.50	3026	0.85	0.03	0.40	4.86	1.28	6.47	1214	4528
Var	**57**	20	**114**	1.6	**68**	17	25	**211**	22	21
European intercomparison study 1994		Na						Zn	S	Cl
Average		27389						11.9	10339	39350

SR %(Between laboratory variability) ca. 25 %

Var – Between laboratory variability; value above 25 % marked in bold; in several cases due to low concentration levels and non critical from a regulatory point of view (e.g. Cd, Cu, Pb, Zn, Sn).

ANNEX 14 Comparison of tank leach test data (Own pH and neutral pH) with regulatory criteria.

Element	BMD* Cat.1	H1 E own** mg/m2	H1 E neutr, mg/m2	H1 Eown/BMD - ***	H1 Eneu/BMD -	N1 E own mg/m2	N1 E neutr, mg/m2	N1 Eown/BMD -	N1 Eneu/BMD -
Al		290.90	29.00			188.50	34.40		
As	41		5.16		0.126		3.16		0.077
Ba	600	43.90	27.90	0.073	0.047	20.60	13.70	0.034	0.023
Cd	1		0.18		0.164		0.16		0.145
Co	29	0.27	0.92	0.009	0.032	0.43	1.14	0.015	0.039
Cr	140	1.77	1.63	0.013	0.012	2.21	2.01	0.016	0.014
Cu	51	0.73	0.88	0.014	0.017	0.51	0.78	0.010	0.015
Mo	14	0.46	1.56	0.033	0.111	0.07	1.15	0.005	0.082
Na		5222	5061			2990	3263		
Ni	50	0.38	1.96	0.008	0.039	0.67	2.09	0.013	0.042
Pb	120	0.09	4.71	0.001	0.039	0.05	6.32	0.000	0.053
Sb	4	0.04	1.17	0.012	0.316	0.02	1.49	0.004	**0.403**
Se	1		2.02		**1.443**		1.33		**0.950**
Sn	29	0.55	2.36	0.019	0.081	0.53	2.12	0.018	0.073
V	230	0.35	2.93	0.002	0.013	0.05	0.74	0.000	0.003
Zn	200	1.92	4.04	0.010	0.020	1.65	1.31	0.008	0.007

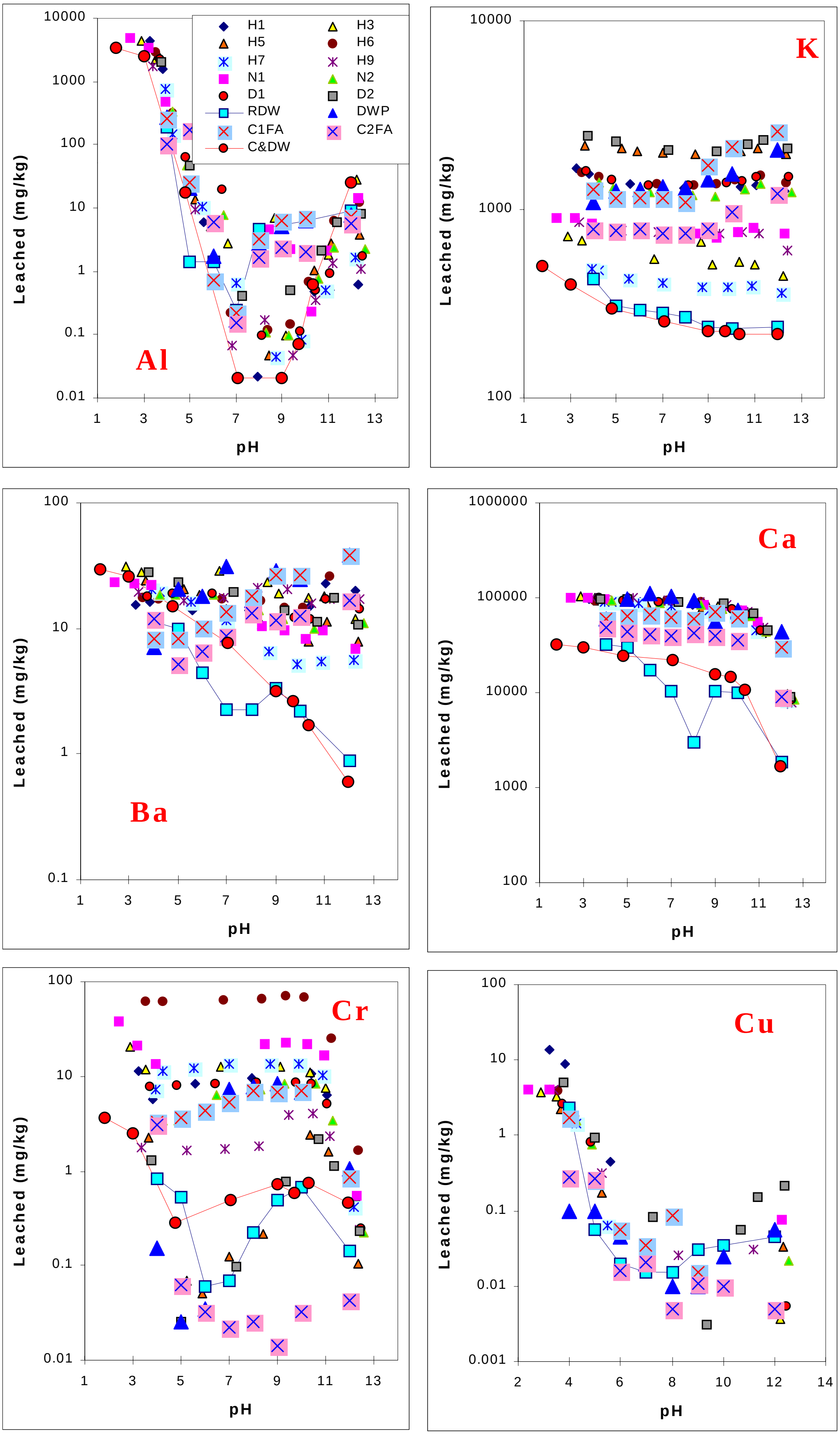
Element		D1 E own mg/m2	D1 E neutr, mg/m2	D1 Eown/BMD -	D1 Eneu/BMD -	H5 E own mg/m2	H5 E neutr, mg/m2	H5 Eown/BMD -	H5 Eneu/BMD -
Al		258.90	42.00			401.00	39.10		
As			2.87		0.070		7.03		0.171
Ba		35.80	25.90	0.060	0.043	23.00	24.80	0.038	0.041
Cd		0.01	0.46	0.013	**0.418**		0.20		0.182
Co		0.19	0.57	0.007	0.020	0.17	1.49	0.006	0.051
Cr		1.20	1.42	0.009	0.010	0.52	4.66	0.004	0.033
Cu		0.46	0.22	0.009	0.004	0.46	0.80	0.009	0.016
Mo		0.06	1.09	0.004	0.078	0.07	2.29	0.005	0.164
Na		2965	3154			2123	5510		
Ni		0.39	1.53	0.008	0.031	0.30	3.51	0.006	0.070
Pb		0.13	6.66	0.001	0.056	0.04	5.36	0.000	0.045
Sb		0.01	1.82	0.003	**0.492**		2.77		**0.749**
Se			1.33		0.950		2.65		**1.893**
Sn		0.54	2.06	0.019	0.071	0.55	1.32	0.019	0.046
V			0.63		0.003	0.42	0.62	0.002	0.003
Zn		1.18	1.14	0.006	0.006	1.18	0.80	0.006	0.004

* BMD - Building Materials Decree; Cat 1 – Category 1 unrestricted utilization
** E own – Release at own pH t=64 days
*** Eown/BMD – Ratio of measured release at own pH relative to Cat 1 of the Building Materials Decree , value above 1 is not in compliance.

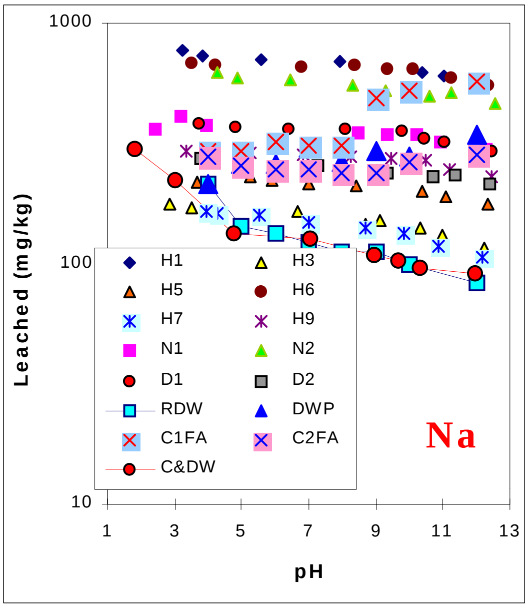
Values in bold reflect critical components

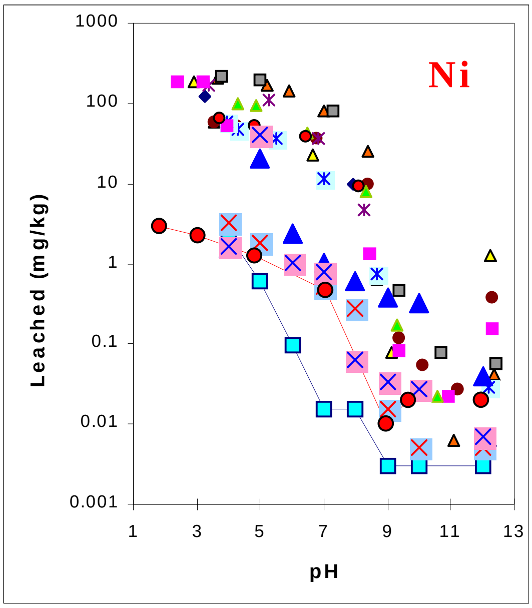
	BMD* Cat.1	N2 E own mg/m2	N2 E neutr, mg/m2	N2 Eown/BMD -	N2 Eneu/BMD -	D2 E own mg/m2	D2 E neutr, mg/m2	D2 Eown/BMD -	D2 Eneu/BMD -
Al		252.00	18.10			265.20	33.40		
As	41		2.90		0.071		4.53		0.110
Ba	600	32.50	21.60	0.054	0.036	25.60	19.90	0.043	0.033
Cd	1		0.20		0.182		0.26		0.236
Co	29	0.53	0.86	0.018	0.030	0.18	0.78	0.006	0.027
Cr	140	1.48	0.78	0.011	0.006	0.26	0.21	0.002	0.002
Cu	51	0.42	0.25	0.008	0.005	0.46	0.32	0.009	0.006
Mo	14	0.06	0.95	0.005	0.068	0.05	2.15	0.004	0.154
Na		5194	4656			2472	2424		
Ni	50	0.97	1.74	0.019	0.035	0.92	2.87	0.018	0.057
Pb	120	0.04	4.77	0.000	0.040	0.03	2.71	0.000	0.023
Sb	4	0.01	1.38	0.002	**0.373**	0.03	1.30	0.008	**0.351**
Se	1		1.24		**0.886**		2.98		**2.129**
Sn	29	0.16	2.52	0.006	0.087	0.23	2.27	0.008	0.078
V	230		0.59		0.003		0.56		0.002
Zn	200	0.82	1.17	0.004	0.006	0.92	1.59	0.005	0.008
		W1 E own mg/m2	W1 E neutr, mg/m2	W1 Eown/BMD -	W1 Eneu/BMD -	W2 E own mg/m2	W2 E neutr, mg/m2	W2 Eown/BMD -	W2 Eneu/BMD -
Al		306.90	26.90			315.70	29.90		
As		0.04	2.49	0.001	0.061	0.19	3.06	0.005	0.075
Ba		25.60	20.50	0.043	0.034	40.30	27.70	0.067	0.046
Cd			0.19		0.173	0.02	0.21	0.017	0.191
Co		0.17	0.73	0.006	0.025	0.18	0.85	0.006	0.029
Cr		2.97	4.91	0.021	0.035	14.00	19.10	0.100	0.136
Cu		0.31	0.60	0.006	0.012	0.38	0.34	0.007	0.007
Mo		0.95	2.90	0.068	0.207	6.27	7.34	**0.448**	**0.524**
Na		1566	1619			1584	1497		
Ni		1.00	1.93	0.020	0.039	1.12	2.27	0.022	0.045
Pb		0.02	3.06	0.000	0.026	0.04	4.41	0.000	0.037
Sb		0.14	1.39	0.038	**0.376**	0.54	2.87	0.146	**0.776**
Se			1.57		**1.121**		1.70		**1.214**
Sn		0.27	3.47	0.009	0.120	0.12	2.56	0.004	0.088
V			0.74		0.003		0.76		0.003
Zn		1.19	15.10	0.006	0.076	0.99	51.60	0.005	0.258

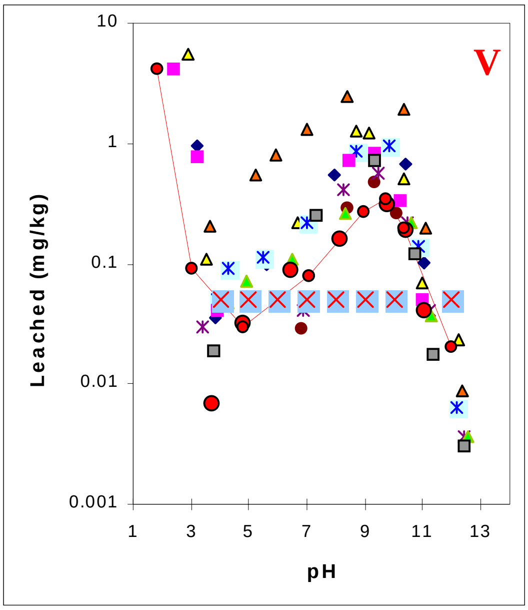
ANNEX 15 Comparison of ECRICEM data with data from other sources.

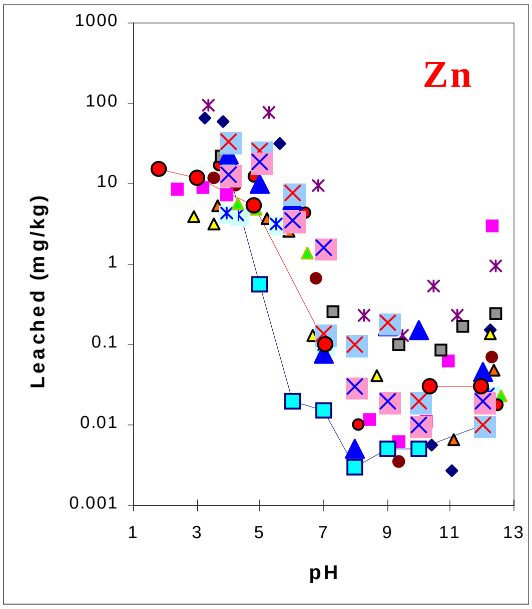


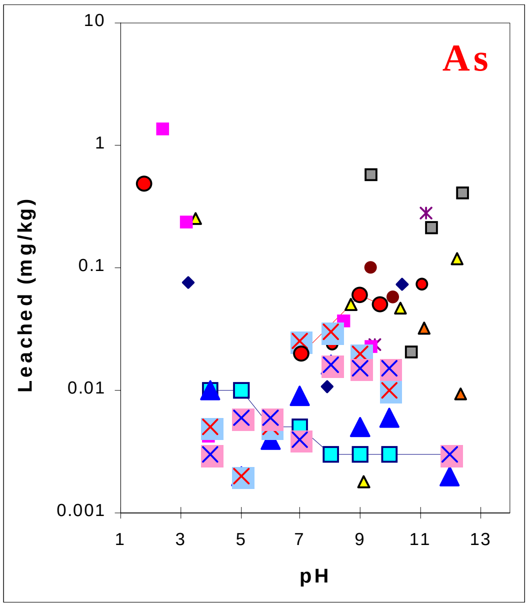
C1FA – Cement –coal fly ash mortar C2FA – Blast furnace slag cement mortar DWP – Drinking water pipe
RDW- Recycled demolition waste ; C&D waste – Construction/demolition waste.

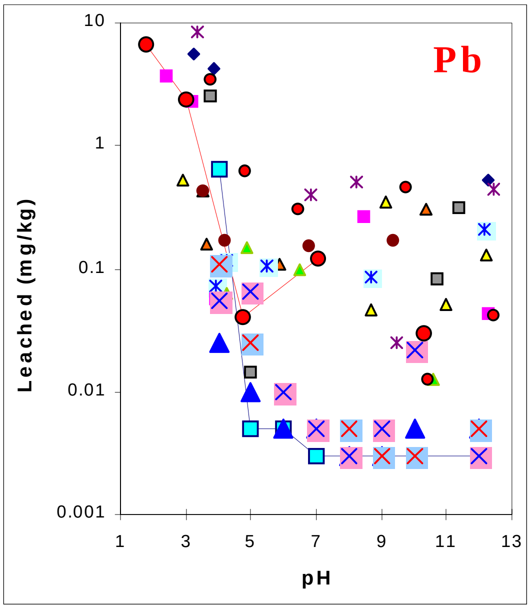

Na
Leached (mg/kg)
1000
100
10
1
3
5
7
9
11
13
pH
H1
H3
H5
H6
H7
H9
N1
N2
D1
D2
RDW
DWP
C1FA
C2FA
C&DW


Ni
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
1
3
5
7
9
11
13
pH


V
Leached (mg/kg)
10
1
0.1
0.01
0.001
1
3
5
7
9
11
13
pH


Zn
Leached (mg/kg)
1000
100
10
1
0.1
0.01
0.001
1
3
5
7
9
11
13
pH


As
Leached (mg/kg)
10
1
0.1
0.01
0.001
1
3
5
7
9
11
13
pH


Pb
Leached (mg/kg)
10
1
0.1
0.01
0.001
1
3
5
7
9
11
13
pH