September 2003 ECN-C--03-092

ENVIRONMENTAL PROPERTIES OF BUILDING MATERIALS IN RELATION TO THE CONSTRUCTION PRODUCTS DIRECTIVE (CPD)

H.A. van der Sloot

Revisions		
A		
B		

Made by:	Approved:	ECN-Clean Fossil Fuels Environmental Risk Assessment
H.A. van der Sloot	R.N.J. Comans	
Checked by:	Issued:	
	J.W. Erisman	

Acknowledgement/Preface

This work has been carried out with support from NEN, Delft Netherlands

CONTENTS

LIST OF FIGURES

SUMMARY

In the Construction Products Directive (CPD) the main issue relating to environment is the essential requirement on hygiene, health and environment, where it is specified that in standards concerning construction products reference shall be made to dangerous substances and ionising radiation. A horizontal approach is considered the best route for the required test development.
The following issues have been addressed: approaches to address environmental impact from construction materials; summary of existing methods for evaluation of composition and leaching of “dangerous substances” from construction materials; summary of available test data on construction materials and scenario approach to assess environmental issues of materials (soil, waste and construction materials).
A generic characterisation approach can de developed for all fine and coarse granular construction materials, which allows to cover a wide range of potential applications of such construction materials. Similarly a generic characterisation approach can be developed for all construction products, which during their service life have a monolithic character. Already a substantial amount of data on a wide range of construction materials is available.
A distinction in characterisation, compliance and on-site verification tests (test hierarchy) provides a useful means of identifying key parameters in the initial process of assessing the environmental behaviour of a material category or class in specific applications. Developing a risk based scenario approach is a most suitable means of identifying key aspects to be addressed in development of regulation and subsequent compliance testing to meet the requirements for regulated substances in the CPD.

1. INTRODUCTION

Already in 1988 the Council has adopted the Construction Products Directive (CPD) with the aim to facilitate an internal free market for construction products by issuing a CE-marking [1]. This is a so-called new approach Directive, which aims to prevent technical barriers in the construction field by defining essential requirements for construction works without reducing existing and justified regulations in member states. Requirements spelled out in the directive relate to mechanical resistance and stability, safety in the case of fire, hygiene, health and environment, safety in use, protection against noise and energy economy and heat retention. The main issue relating to environment is the essential requirement on hygiene, health and environment. In the CPD, it is specified that in standards concerning construction products reference shall be made to dangerous substances and ionising radiation. The scope of the Directive is limited to the service life of materials. The recycling stage and the “end-of-life” aspects are not addressed here. In the field of construction materials more than 40 Technical Committee’s (TC) are active in CEN with a main focus on technical specifications. Many of these are confronted with the request to deal with dangerous substances in relation to the CPD. As CEN TC‘s are largely autonomous, there is the chance that each individual TC will develop its own test(s) to address the various questions. Although it is recognized that there are differences in material characteristics as well as differences in use of the same material, it is also clear that a wild growth of different tests for the wide range of construction materials will require significant funds, manpower of experts and may be counterproductive from a regulatory point of view. This had led to considerations to try to harmonise the test development by CEN TC’s needed to address the questions posed by the CPD.

The following issues are relevant in this context

- Approaches in addressing environmental properties of construction materials.

There are different manners how to arrive at methods for testing. One is to use a vertical approach in which all TC’s are fully autonomous in their development of what ever test they choose to address the environmental properties of construction products used in a specific sector. This approach may lead to rather different choices. Another approach is to identify what main goals needs to be reached for the entire construction field using the current state of knowledge in assessing environmental impact resulting from use of construction products including secondary materials in construction applications. In this approach, a scenario type of evaluation is used, in which basic characterisation of material properties forms the starting point and flexibility for specific uses of the same material or comparability in assessment of different materials for the same application can be guaranteed. The latter is the preferred approach as it creates a common basis of reference with a better scientific background than arbitrary choices in test conditions, a common basis for regulatory control and development of compliance test with reference to more elaborate test data. For other issues in relation to environmental or health aspects of construction products, such as radiation and asbestos also harmonised methods need to be developed. In view of the nature of these properties, which require measurement of a property, this is easier achieved than in the case of release of dangerous substances.

- **Summary of existing methods for evaluation of composition and leaching of “dangerous substances” from construction materials.**

There is a need to see what differentiation in environmental testing currently exists in the entire construction products field. This then allows to identify the option to arrive at harmonised procedures possible suitable for several products with similar characteristics. A limited inventory of activities of different CEN TC’s in the field of leaching is already available. This covers TC’s such as TC 227 (Road materials) TC 51 (Cement and building limes), TC 104 (Concrete), TC 154 (Aggregates) and TC 164 (Drinkingwater pipes). In addition, the release behaviour of widely different construction products were studied using comparable test methods in the framework of EU project Harmonisation of Leaching/Extraction Tests [2] and subsequent studies [3,4,5,6].

- Summary of available test data on construction materials.

There is already a significant amount of information as a result of EU projects, industrial initiatives and nationally funded work in relation to the drafting of regulation (e.g. Mammoet study for the Dutch Building Materials Decree [7]) as well as industry needs to understand the release controlling mechanisms. In table 1, a list of materials and test is given for which test data on different levels of detail are available. More data is expected to be available, but not in such a readily assessable form. Creating a generally assessable database/ expert system with this type of information will avoid unnecessary duplication of work and allow (new) member states with less developed infrastructure for environmental testing to catch on faster.

- Scenario approach to environmental issues of materials (soil, waste and construction materials).

In the framework of Dutch national programmes in preparation of the Building Materials Decree, a range of building materials have been studied using more sophisticated leaching tests. In the framework of several EU research projects, more detailed leaching tests have been applied and in particular in the EU project Harmonisation of Leaching/Extraction tests several characterisation leaching tests including the pH dependence test have been applied to different materials covering soil, contaminated soil, sludge, waste, sediments, construction materials, aggregates and impregnated wood. This comparison has led to the conclusion that there are many similarities in the leaching characteristics of inorganic elements in specific classes of materials. In addition, systematic relationships between different tests have been established. Recent work on cement mortars has shown very systematic leaching behaviour of world wide cement mortars. The more extended leaching tests provide the basis for a scenario type of approach to assess environmental impact through modelling. This information can be related to generic environmental quality criteria as set by governments. These type of more extended characterisation tests provide information on processes and controlling factors relevant for management, if materials do not comply directly with existing or future legislation. The more detailed testing information provides a sound basis for developing more targeted, simple testing for quality control and compliance purposes (hierarchy in testing). From a testing and environmental impact assessment point of view, a distinction is needed between granular materials (percolation dominated) and monolithic materials (diffusion dominated release).

2. POTENTIAL AND ADVANTAGES OF A HARMONISED APPROACH

A generic characterisation approach can de developed for all fine and coarse granular construction materials, which allows to cover a wide range of potential applications of such construction materials. From the basic characterisation data for granular materials, compliance protocols can be derived for various uses of materials, which only need to be different, when this is strictly needed to meet specific objectives. Reporting data in relation to the characterisation test data provides a basis to reduce frequency of testing by proven compatibility with the basic data set.

A generic characterisation approach can be developed for all construction products, which during their service life have a monolithic character. From the basic characterisation data for monolithic materials, compliance protocols can be derived for various uses of materials, which only need to be different, when this is strictly needed to meet specific objectives. Such reasons may be particular behavioural aspects of typical material like sintered brick and asphalt concrete. These widely different materials can be tested with the same basic procedure as there is no fundamental difference in the major release mechanism. Reporting data in relation to the characterisation test data provides a basis to reduce frequency of testing by proven compatibility with the basic data set.

The advantage of such a harmonised approach is that a consistent regulatory framework can be developed, in which different material that can be used in the same application can be judged on the same basis, rather than by comparing apples and pears in case different tests are developed for concrete than for brick.

Such a harmonised approach will undoubtedly lead to a significant level of comparability between different construction products, which implies that information gained in one are will benefit another and visa versa.

A significant cost benefit will be the avoided cost of standardising too many standards. In addition, the clarity and transparency of the testing system will reduce debate, which in case of arbitrary choices will flare up every time a new product reaches the market.

3. RECOMMENDATIONS

Evaluating environmental properties of building materials and raw materials for use in construction requires a scenario approach to be able to decide which properties are relevant in relation to environmental standards and which type of tests are needed to assess the environmental impact as close as possible in accordance with practice. This is particularly relevant for situations where the same material is applied in different circumstances with different environmental impact. Using a scenario approach is a most suitable means of identifying key aspects to be addressed in development of regulation and subsequent compliance testing.

A distinction in characterisation, compliance and on-site verification tests (test hierarchy) provides a useful means of identifying key parameters in the initial process of assessing the environmental behaviour of a material category or class in specific applications. It facilitates the selection of the most appropriate short test to verify compliance with regulatory criteria and, if needed, quick screening methods to check key properties relevant for process control. The characterisation up-front provides an understanding of the environmental properties of materials under a variety of exposure conditions and factors influencing the individual behaviour of elements and different time scales, thus providing means to actively manage and control a material's behaviour in the short and long term. This type of long term behaviour assessment is the key to sustainable development.

Characterisation of leaching behaviour is important:

- to identify factors controlling release for improvement of product performance
- identify critical constituents in a material category or type for service life, recycling stages and "end-of-life" scenarios
- identify optimal conditions for quality control by compliance testing
- as basis of reference in evaluating compliance test data
- for modelling of solubility controlling phases.

In the framework of the CPD, leaching test are important to address the issue of dangerous substances and environment. It makes no sense for 40 or more CEN Technical committees on construction materials to each develop their own leaching test. A process of horizontal standardisation is called for, in which a hierarchy in testing may prove very useful to focus on key issues in the different material categories – concrete, sintered bricks, lime-silicate bricks, asphalt concrete, etc. Similarities in leaching behaviour between material classes can avoid unnecessary duplication of work and result in a more consistent basis for regulatory control than many different unrelated test results.

Evaluation of construction products should preferably not be restricted to the service life only. It is important to address recycling and end of life situations as well, because undesired leaching in these stages should as a rule be avoided beforehand in sustainable development.

In view of the measures to produce constant quality products in the construction sector, inherently consistent leaching behaviour can be expected. This implies that characteristics once established are not likely to change rapidly. Only after major changes in process operation or use of alternative raw materials.

The cost of characterisation is limited relative to the cost of long-term quality control. In addition, characterisation provides a possibility to reach cost savings in frequency and number of parameters to be tested, which will prove more effective in the long run. Finally, characterisation data allow identification of causes for deviations from "normal" behaviour, which than can lead to management measures to cure the problem and cheaper or better production techniques.

REFERENCES

1. Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products.

2. Harmonization of leaching/extraction tests, 1997. Studies in the Environmental Science, Volume 70. Eds. H.A. van der Sloot, L. Heasman, Ph. Quevauviller, Elsevier Science, Amsterdam, 292 pp.

3. Sloot, H.A. van der, D.S. Kosson (2003): A unified approach for the judgement of environmental properties of construction materials (cement-based, asphaltic, unbound aggregates, soil) in different stages of their life cycle. Proceedings WASCON 2003 Conference, San Sebastian, Spain, 2003.

4. Kosson, D.S., H.A. van der Sloot, F. Sanchez and A.C. Garrabrants (2002): An integrated framework for evaluating leaching in waste management and utilization of secondary materials. Environmental Engineering Science (19) 3, 159-204.

5. Sloot, H.A. van der (2003): Horizontal standardization and harmonization of leaching test methods for waste, secondary raw materials, construction materials and (contaminated) soil. Proceedings WASCON 2003 Conference, San Sebastian, Spain, 2003.

6. Sloot, H.A. van der, P. Seignette, R.N.J. Comans, A. van Zomeren, J.J. Dijkstra, H. Meeussen, D.S. Kosson, O.Hjelmar (2003): Evaluation of environmental aspects of alternative materials using an integrated approach assisted by a database/expert system. Conference proceedings "Advances in Waste Management and Recycling, September 2003, Dundee, 769-790.

7. *Building Materials Decree*. Staatsblad van het Koninkrijk der Nederlanden, 1995, 567.

8. Hjelmar, O. (2003): Environmental performance of alternative raw materials. Advances in Waste Management and Recycling, September 2003, Dundee, 653-668.

9. Sloot, H.A. van der, A. van Zomeren, J.J. Dijkstra, D. Hoede, J. Jacobs, H. Scharff (2003): Prediction of long term leachate quality and chemical speciation for a predominantly inorganic waste landfill. 9th International Waste Management and Landfill Symposium, 6-10 October 2003, Sardinia.

10. Meeussen, J.C.L., ORCHESTRA: an object-oriented framework for implementing chemical equilibrium models. Environ. Sci. Technol. 2003, 37, 1175-1182.

Table I. SUMMARY OF PRIMARY AND ALTERNATIVE CONSTRUCTION MATERIALS FOR WHICH MORE EXTENDED LEACHING INFORMATION IS ALREADY AVAILABLE (Sources: Mammoet onderzoek, RIVM studies, EU Harmonisation work, ECN research, Building Materials decree certification, EU projects, other.)

	Characterisation				Compliance		Other											Sum
	pH stat	Column	Tank	CGLT*	Granular	Monolith	Availability	Concise	Hac	Swiss	TCLP	DIN	AFNO	CaCl2	NaNO3	EDTA	SCE	
Materials No of e	8	8	8	8	1-2	3	2	4	1	1	1	1	1	1	1	1	4	
	PrEn14429	PrEn14405/ NEN7343	NEN 7345	NEN 7347	EN-12457	WI292010	NEN 7341											
Synthetic Aggregates (coal fly ash, mining waste, etc)	10	8		2	6			6										32
Blast furnace slag	2	8	10				2											22
Bottom ash (coal)		10			20													30
Bricks (ceramic)	4		10			10	5											29
Clay bricks	2		5			5	5											17
Compost	2	2			2									2				8
Cement mortar	45		24		20	20	45	10										164
Concrete	6		12				10											28
Construction debris	4	30			10													44
Contaminated soil	6	12			5			2	2					2	2	2	2	35
Drinking water pipes	2		2				2											6
Lime silicate bricks	2		12			5	2											21
MSWI residues (bottom ash, fly ash APC residues)	15	20		2	10		10	5	3	3	25	15						108
Pb/Zn slag	5	5			5		5		5	5	5	5	5					45
Phosphate slag	2	10	2	2			2											18
Sediments (river, lake, canal)	10	2			3		3										2	20
Soil (various types of natural soil: sand, loam, clay)	2	2						2	2					2	2	2	2	16
Steel slag	4	48		6	6		2											66
Vitrified MSWI fly ash	5	4	2		3		3				2	2						21
No of tests	128	161	79	12	90	40	96	25	12	8	32	22	5	6	4	4	6	730 tests
No of Extracts (average)	1024	1288	632	96	90	120	96	100	12	8	32	22	5	6	4	4	24	3563 extracts
No of elements (average)	15360	19320	9480	1440	1350	1800	1440	1500	180	120	480	330	75	90	60	60	360	53445 element data

* CGLT = Compacted Granular Leach Test; ** Concise test = extended compliance test with two L/S and 2 pH conditions

APPENDIX A FIGURES ILLUSTRATING SPECIFIC ASPECTS

Suitability for specific test methods to address release from construction products. In Figure 1 results obtained with the tank leach test are given. The release expressed as a surface area related phenomenon is applicable to a wide range of monolithic construction materials. It provides information on release mechanism as well as released amount per unit area. The test result can be used as basis for modelling long term behaviour.

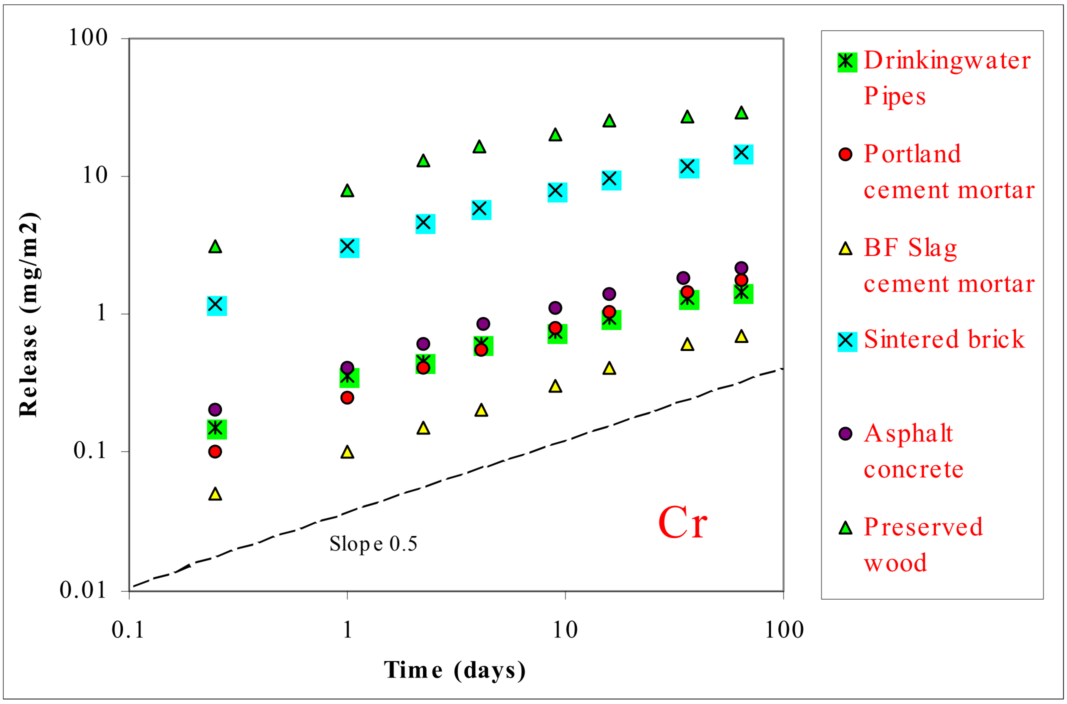

Figure 1 *Release of Cr from a wide range of construction materials using a monolith tank leach test (NEN 7345) illustrating the similar characteristics of leaching from different materials*

The chemical speciation of constituents is crucial to understand the behaviour of different regulated substances. In figure 2 the leaching behaviour of Cr from a range of materials is presented using the pH dependence leaching test results (PrEN 14429). The chemistry that controls leachability gives a good indication of solubility controlling phases in the product matrix and its sensitivity to alterations in products resulting from carbonation and remineralization processes. A Cr release in the pH range pH > 7 generally indicates release of Cr (VI). The difference in Cr leachability between blast furnace slag cement and Portland cement is quite substantial. In BFS slag cement, the reducing properties of the cement ensures reduction of any Cr VI present to Cr III.

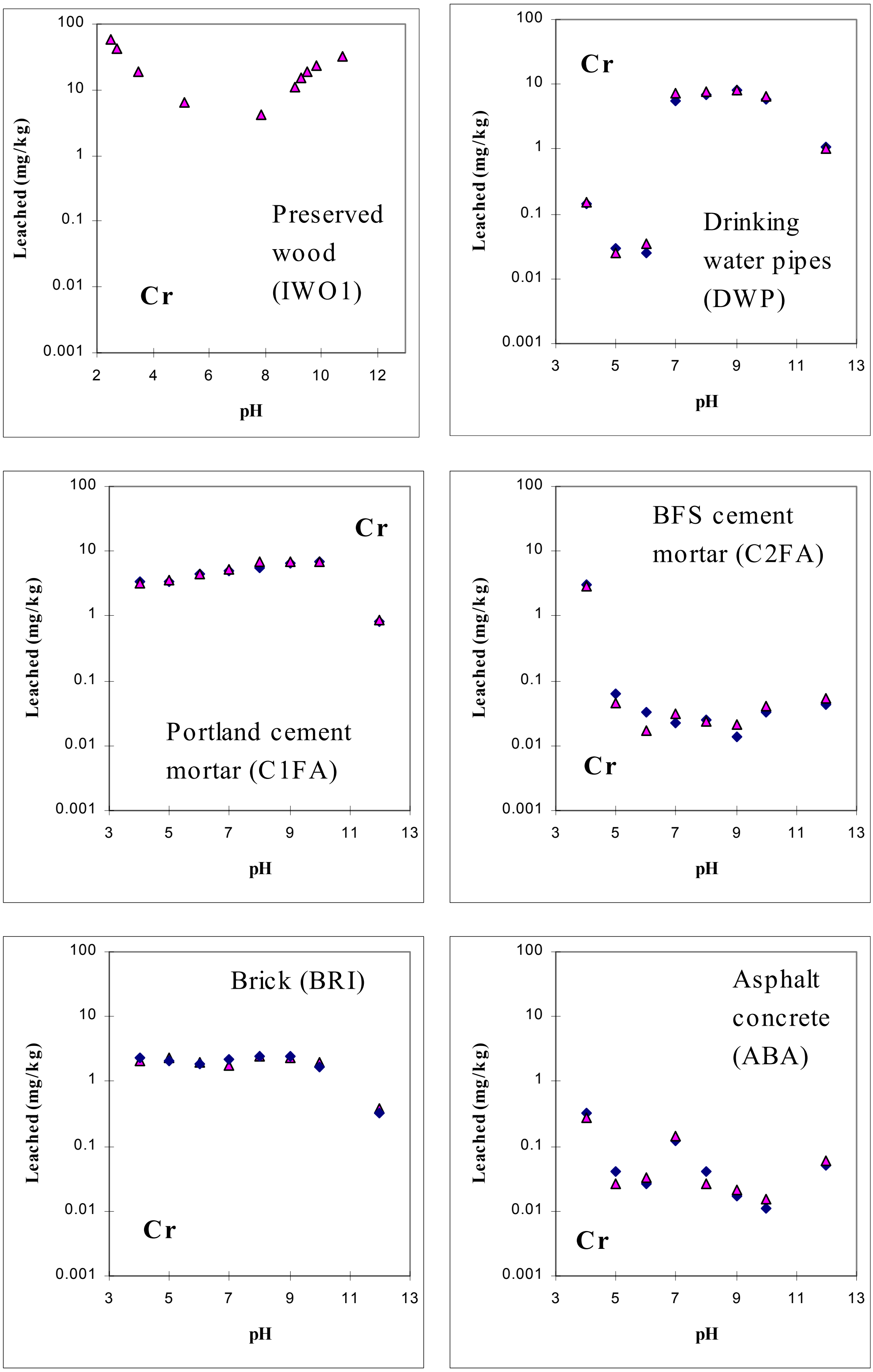

Figure 2 *Leaching behaviour of Cr from a wide range of construction materials as a function of pH (PrEN 14429) illustrating the differences in leaching behaviour of Cr. This is largely related to the proportion of Cr VI relative to Cr III in the material. Information from this test is relevant for exposure to other pH environments*

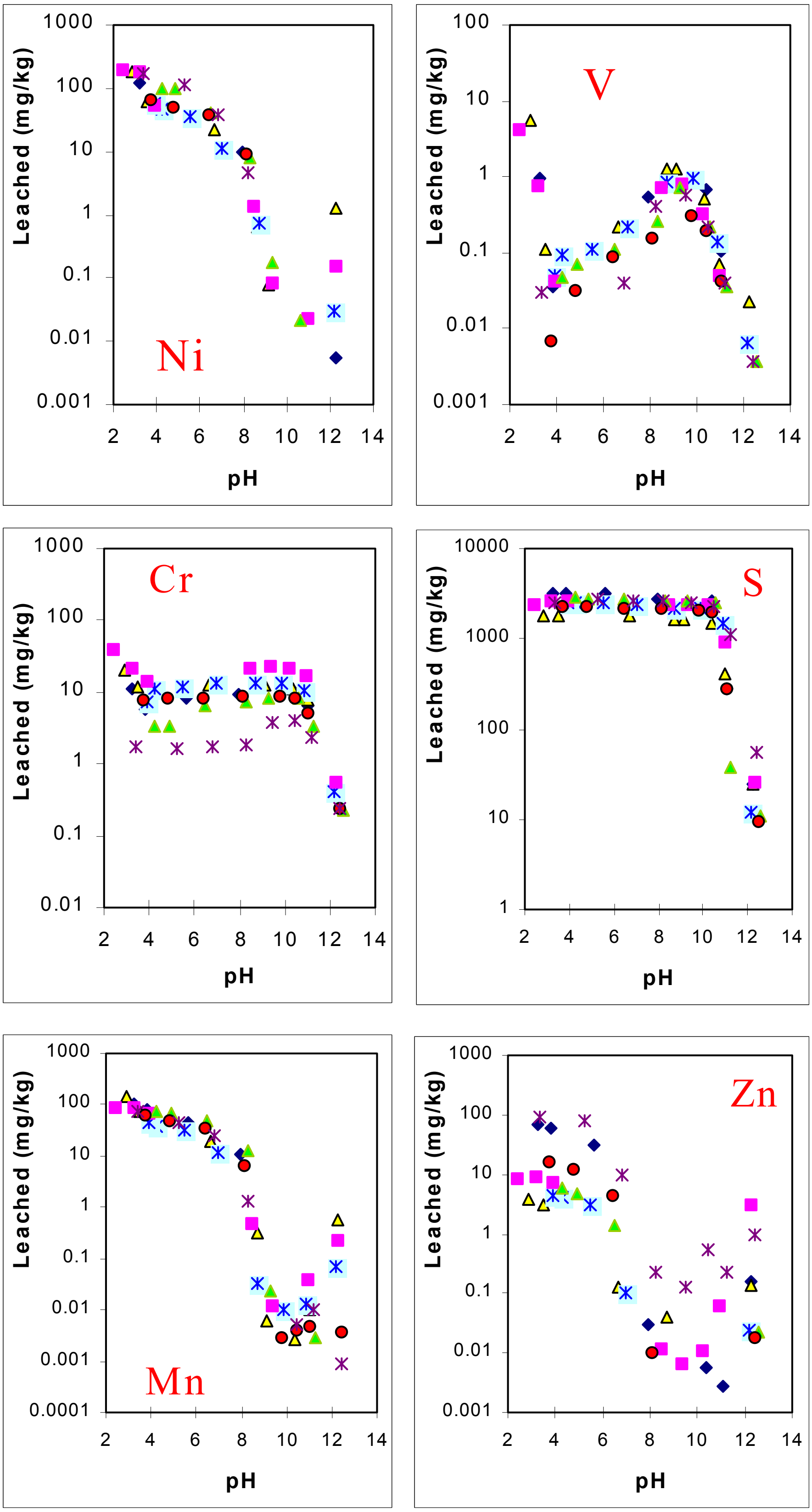

Figure 3 *Leaching of selected elements from crushed portland cement mortars as a function of pH illustrating the very systematic leaching behaviour of cement mortars (PrEN 14429).*

Construction materials produced in large-scale installations have the tendency to produce quite constant quality products. In figure 3 this aspect of evaluating regulated substances is illustrated for cement mortars from different sources, which implies that variability within one production facility is most likely even less than shown here. The mineral phases controlling solubility within the cement matrix can often be assessed for such very consistent data sets. Once controlling phases can be identified, more reliable prediction of long-term behaviour becomes possible.

For granular materials, such as materials used in road base applications, the percolation test (PrEN 14405) provides very useful information as the liquid to solid ratio (L/S) can be used as a measure of time by using the infiltration rate, the height and density of the material (see figure 4). From the test mechanistic information can be obtained. The Cu leachability from MSWI bottom ash reaches a plateau at L/S > 1. This implies that the readily leachable Cu fraction is depleted. For prediction of long term behaviour this is a very important observation. In case of incinerated sewage sludge, an increase in CU leachability is observed, which is related to a drop in pH during the percolation test (material has a rather low buffer capacity).

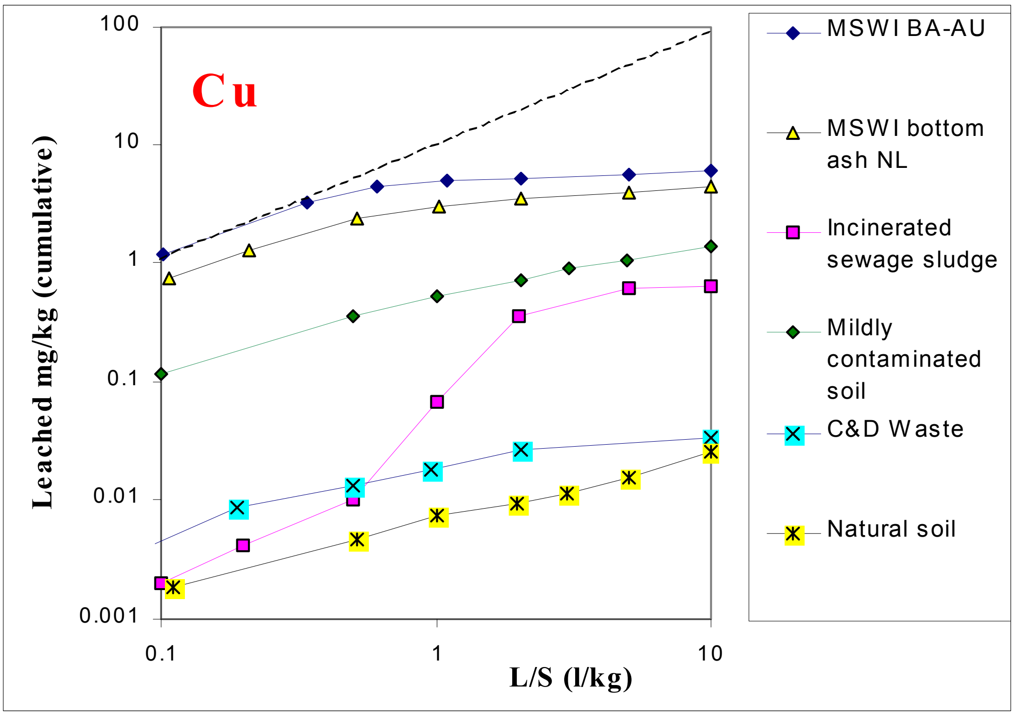

Figure 4 *Leaching of Cu from several secondary raw materials used in construction applications as a function of L/S in a percolation test (PrEN 14405).*

Characterisation as described by pH dependence, percolation and tank leach test provides the understanding and background needed to make a proper scenario description, develop a regulatory framework, identify the relevant constituents for QC purposes in a given construction product and provide a basis for selecting suitable compliance test protocols for quality control testing. The compliance test data should relate as closely as possible to the characterisation data to make as much use as possible from previous obtained information. Building the database increases the level of understanding of the materials properties and variability and will likely lead to reduction in frequency of testing and number of parameters to be tested. In figure 5 the relationship between characterisation and compliance is illustrated.

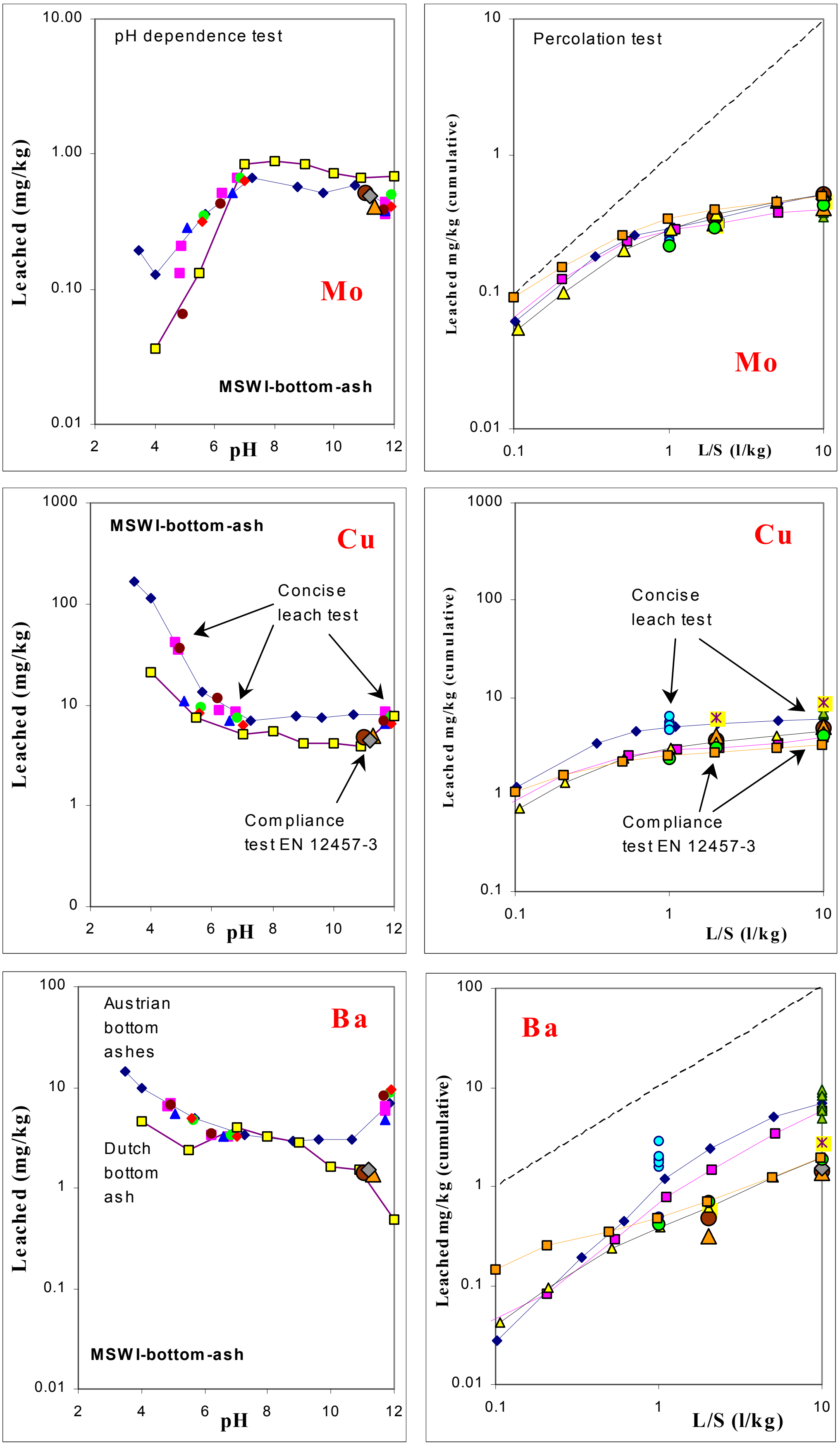

Figure 5 *pH dependence test data and percolation test data for MSWI bottom ash as characterisation leaching tests in comparison with compliance leaching tests data for the same material.*

Based on the scenario approach as applied for the development of criteria (Annex II) in the Landfill Directive [8] a similar approach can be adopted for construction products. The source term for release from a specific application of construction materials is the key property that needs to be determined. The part of the impact assessment that describes the interaction of released constituents with sub-soil and transport to groundwater is the same for any type of application or material applied on/in soil. Forward modelling using a well defined source term and its impact on a pre-defined target (e.g. groundwater next to the application) and back calculation of acceptance limits based on the ratio between calculated impact and acceptable impact, will provide guidance in setting acceptance criteria for a limited selection of scenarios of application. Once the criteria are known, the test results can be compared with the limit values. In figure 6 such a comparison with regulatory criteria is shown.

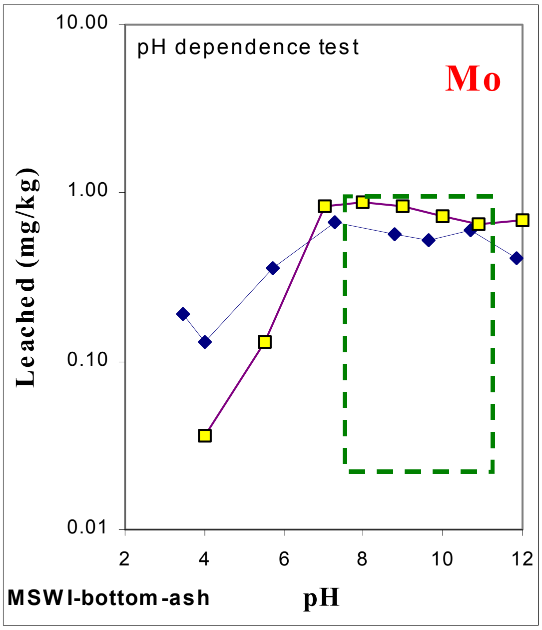

Figure 6 *pH dependence test data with relevant pH domain for normal use. The box is defined by the right vertical line as the highest pH of the material itself, the left vertical line reflects the end pH in the long term. The horizontal upper line represents the crossing with the highest measured value within the defined pH range or the regulatory limit value. The lower horizontal line represents the detection limit.*

An outline for the framework to judge environmental implications of material use in different scenarios of application is given in figure 7. In the framework various aspects such as characterisation and compliance (hierarchy in test use), lab-field relationships [9], external influences and infiltration issues are addressed. A key aspect in all situations is a proper problem definition. A (preferably limited) number of scenarios should be developed to quantify impact. As more detailed characterisation of leaching behaviour of material types forms the key to a proper impact evaluation and identification of consistent material behaviour, a database/expert system integrating many aspects relevant in the judgement of material will be very helpful in providing efficient and more comprehensive answers to questions.

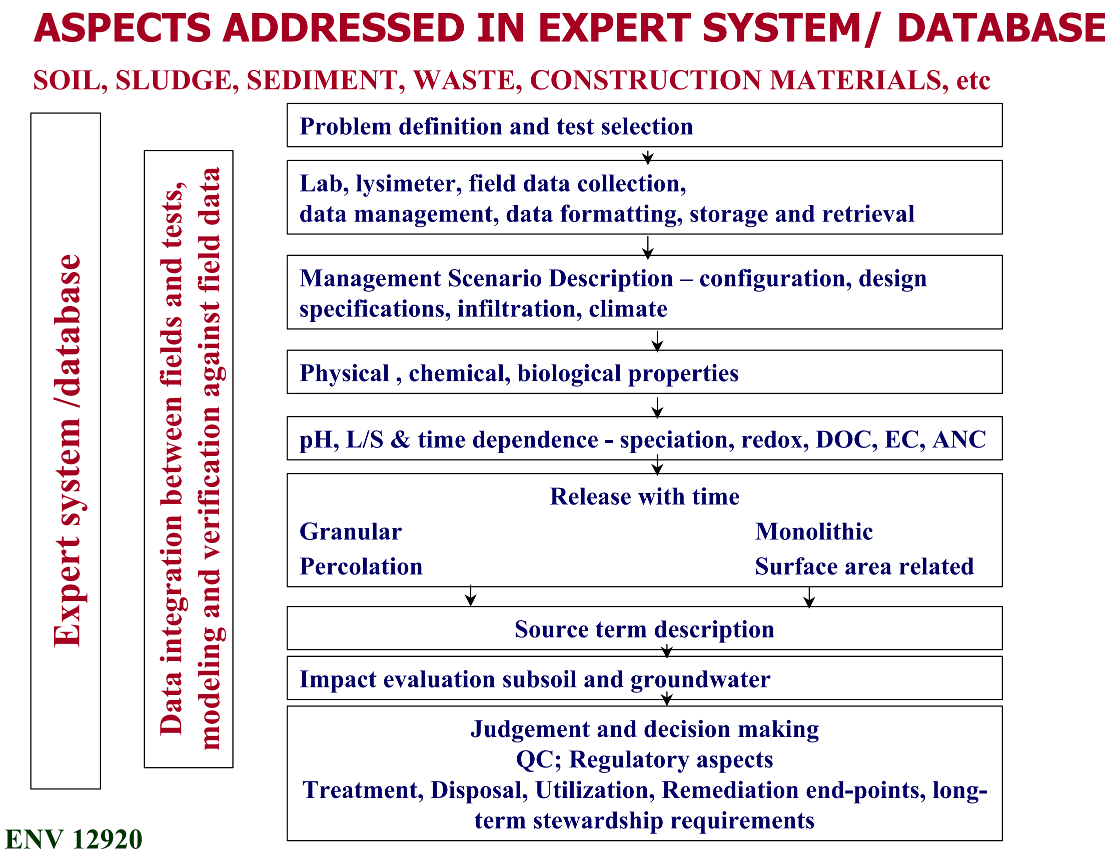

Figure 7 *Integrated evaluation scheme for a wide range of materials applied on / in soil or in water.*

Different stages in the building process call for different types of evaluation (see figure 8). Materials may perform well in service life, but may lead to limitations during recycling or "end of life" conditions. From a sustainability point of view, it would therefore be best to incorporate the entire life cycle of a material in the primary evaluation. The characterisation information described before will provide the basis for such an assessment as for instance the pH dependence test is carried out on size reduced material. This test reflects the material release changes due to carbonation in size-reduced state (construction debris).

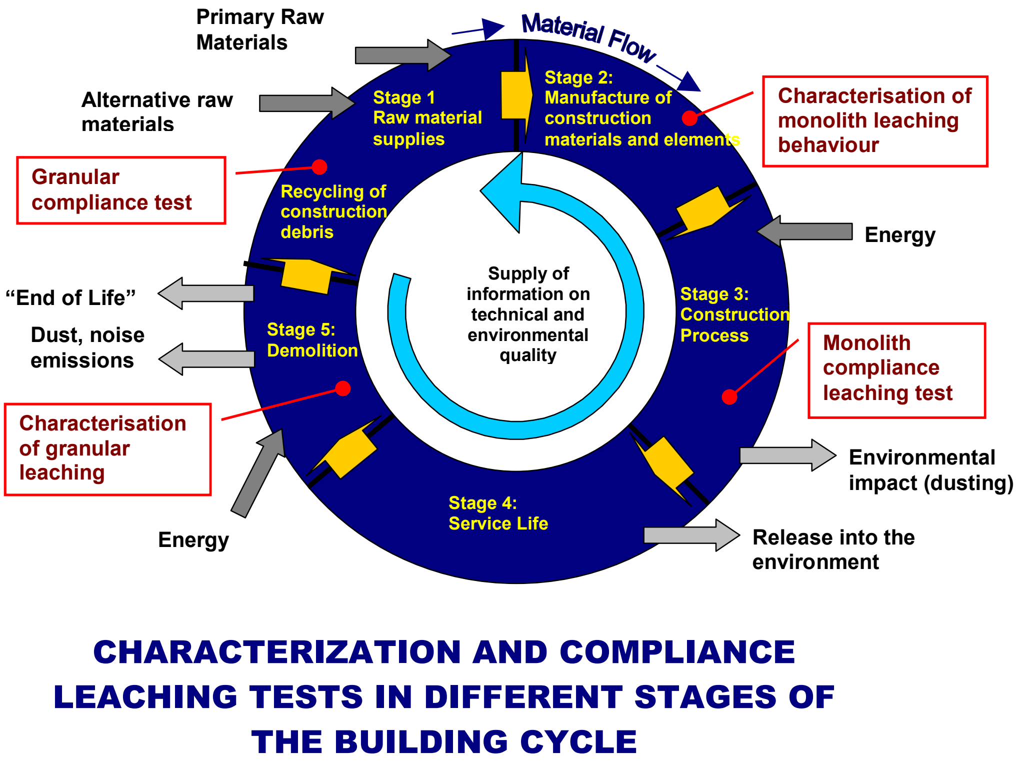

Figure 8. *Integration of release testing in the life cycle of building materials.*

An integrated evaluation of the source term for granular materials is based on the combination of pH dependence test and percolation test. Different scenarios of exposure of the same material are highlighted by the boxes in the graphs (see figure 9). The chemical speciation is part of the evaluation adding to the certainty of long term prediction.

A similar integrated evaluation for monolithic materials is based on the combination of the pH dependence leaching test and the tank leach test. Different scenarios of exposure for the material in service life, in recycling and in "end of life" conditions is given in figure 10 for cement mortars. This figure also shows the consistent leaching behaviour of Zn from more than 50 cement mortars from world-wide origin. Chemical speciation modelling allows identification of solubility controlled release in a dynamic leach test such as the tank leach test. The cumulative release levelling off at contact times > 10 days is an indication of such phenomena.

The integrated evaluation for both granular and monolithic material can result in source term descriptions for soil and groundwater impact in a wide range of scenarios when scenario specific aspects (infiltration, temperature, etc) are taken into consideration.

New modelling approaches (Orchestra [10]) are in development to assess pore water concentration profiles in exposed specimen, pore sealing due to carbonation and concentration build up in an external solution under normal atmosphere, inert atmosphere or increased CO_2 levels (soil air).

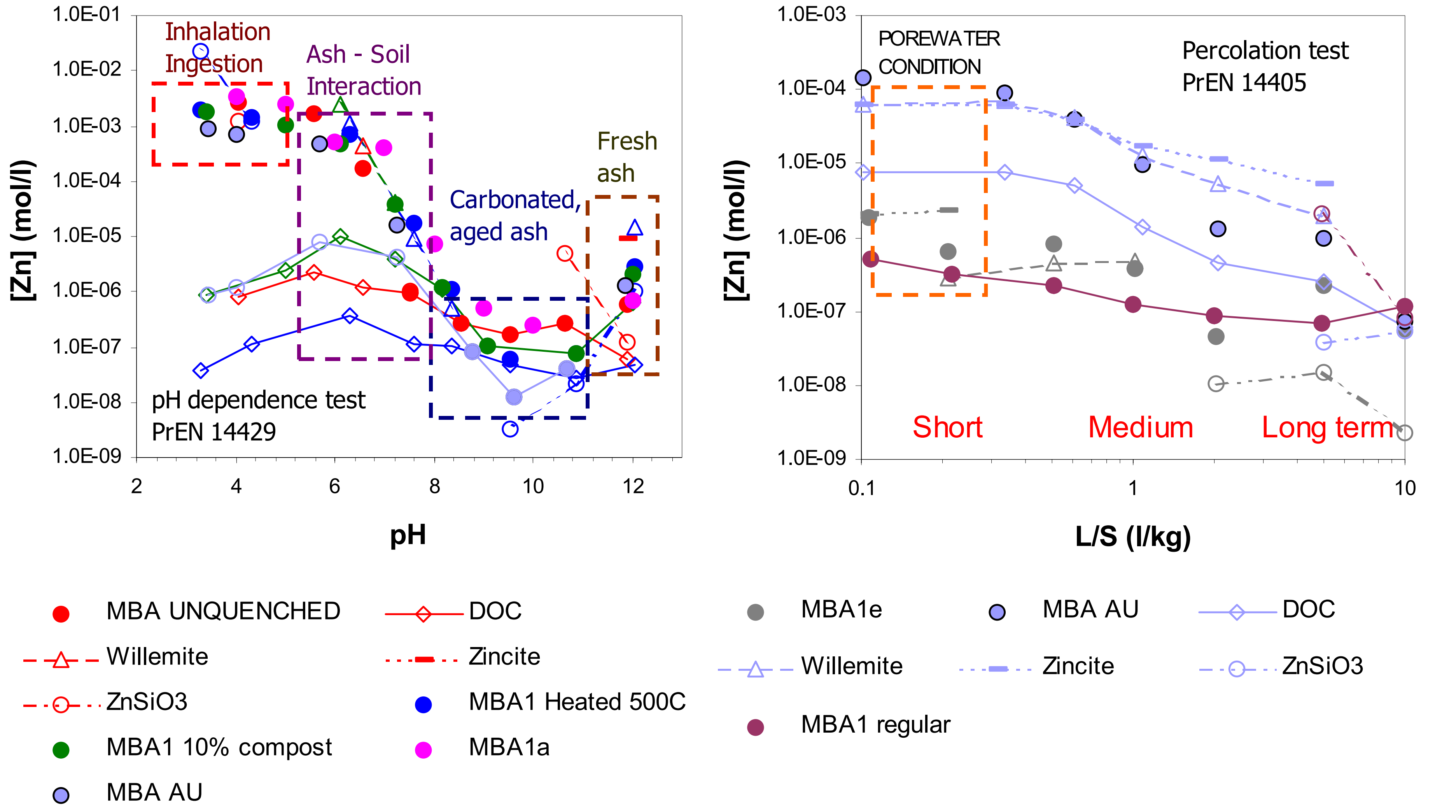

Figure 9. Integrated evaluation of granular construction materials (chemical speciation included). From pH 9 to 11, Zn is 100% DOC associated. In the high pH bottom ash (MBA AU) Zn is controlled by willemite (ZnSiO4). In the aged ash (MBA1 regular), Zn is fully DOC associated.

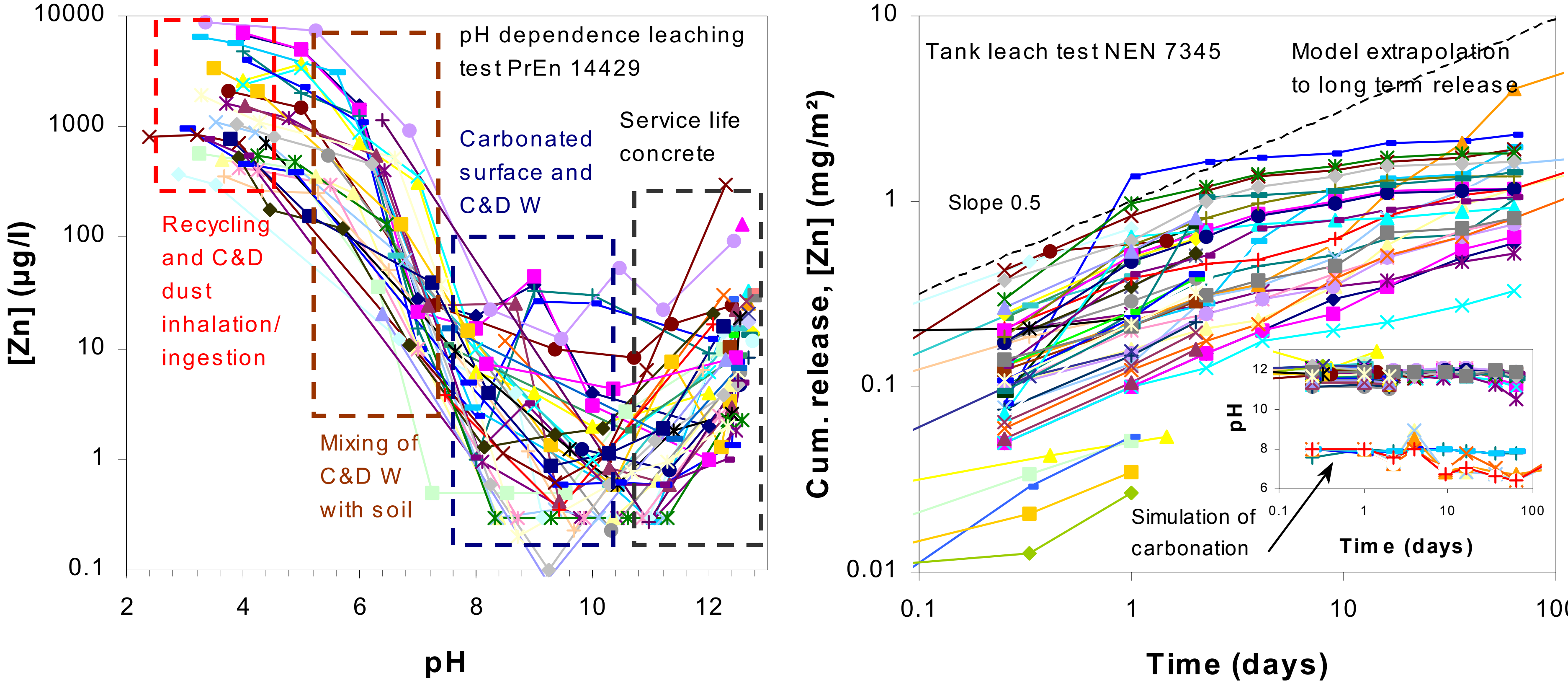

Figure 10. Integrated evaluation of monolithic construction materials with scenario conditions indicated. The insert shows the range of exposure conditions employed in the testing (own pH pH >11; imposed pH at pH about 8).