

RELEASE FLUXES OF MSW GLASSES: SUGGESTED APPROACH

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## FOREWORD

Reports 1 (State of knowledge on waste glasses; June 1998) and 2 (MSW glasses: the opinion of selected experts; October 1998) were presented to the working group for the revision of the Swiss Regulation on Waste Management<sup>a</sup> (hereafter referred to as "working group") during its previous session (November 11, 1998).

Amongst others, it was mentioned that updated TVA/OTD guidelines taking into account the characteristics of MSW glasses would require the scientific assessment of two key parameters, namely:

- (a) the **static picture** of the MSW glasses, *i.e.* their composition, and in particular their content in toxic metals,
- (b) the **dynamic picture** of the MSW glasses, *i.e.* their long-term behaviour when subject to chemical alteration.

The approach to be followed to assess these two key parameters includes, amongst others, the **comparison** of the static and dynamic pictures of the MSW glasses with **natural and anthropogenic concentrations and fluxes** of toxic species in our environment. To achieve this goal, a large campaign of analyses of representative MSW glasses has been started in December 1998; this campaign will be completed in Summer 1999.

Meanwhile, some scenarii have been explored with theoretical data to estimate the feasibility of this comparison. This short document presents briefly the **preliminary results of the estimated fluxes**.

The document does not represent an ultimate report on the question; instead, it is strictly intended to be discussed within the frame of the working group during its next working session. The response of the members of the working group to this approach will be taken into account for the preparation of report 4 (Long-term stability of MSW glasses; Autumn 1999).

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(a) Arbeitsgruppe "TVA-Änderung im Bereich Verbrennungsrückstände"; this working group includes representatives from BUWAL, the industry and the academic institutions.

## SYNOPSIS

The present scenario proposes to consider the effects of the reuse of MSW glasses in road construction. It involves a series of overestimating and penalising assumptions on the concentrations and fluxes of toxics, and of the external conditions influencing the corrosion of MSW glasses. Consequently, the results represent upper limits which could not be reached under every-day conditions.

The following assumptions have been applied :

- (1) All swiss MSW incineration plants are replaced by alternative high-temperature in-line or post-process vitrification/inertisation plants.
- (2) The amount of toxic elements in MSW glasses (static picture) is estimated from existing experimental work.
- (3) MSW glasses are reused as foundation layer for road construction.
- (4) The penalising corrosion rate of the MSW glass is extracted from literature data obtained with an analog MSW glass.
- (5) The release flux of toxics from MSW glasses (dynamic picture) is conservatively estimated from the worst situations.
- (6) The static and dynamic pictures of MSW glasses are compared to realistic ranges of concentrations and fluxes of toxic metals in natural and anthropogenic reservoirs.

The results of this approach show that:

- **The concentrations of toxic metals in MSW glasses do not inform on their quality for landfill disposal, on the basis of the actual regulation.**
- **The estimated time of life of MSW glasses reused for road construction is exceptionally high.**
- **MSW glasses are not necessarily more contaminated than some natural/anthropogenic materials in our surrounding.**
- **The concentrations of toxic elements released from MSW glasses are in the order of magnitude of the concentrations determined in natural, unpolluted reservoirs.**
- **The quantities of toxic elements released in the environment are very low and in the order of magnitude of the quantities generated by natural and anthropogenic fluxes.**

Of course, the results presented in this report are only rough estimates, based on theoretical considerations, assumptions and experimental data. Nevertheless, the concept underlying behind the proposed scenario appears to be pertinent.

## INTRODUCTION

The proposed approach to compare the release fluxes of toxics from MSW glasses<sup>a</sup> and the natural/anthropogenic fluxes of toxics in our close environment is summarised in the following scenario:

- (1) Estimation of the **total mass of MSW glasses** that would be produced in Switzerland if all actual MSW incineration plants would be (i) replaced by in-line processes<sup>b</sup> or (ii) updated with post-processes<sup>c</sup>.
- (2) Estimation of the **content of toxic elements** in these MSW glasses.
- (3) Estimation, with a corrosion constant taken from the literature, of the **release fluxes of these toxic elements** under a single specific working condition: the reuse of MSW glasses as backfill layers in road construction.  
 This step requires that (i) a pertinent analog, (ii) a pertinent corrosion condition, and (iii) a pertinent corrosion constant be selected.
- (4) Estimation of the **natural and anthropogenic concentrations and fluxes of toxic elements** in the environment.
- (5) **Comparison of the estimated fluxes** described in points (3) and (4).

## MSW GLASSES

The estimation of the total mass of MSW glasses that would be produced in Switzerland has been achieved according to the following criteria:

### • MSW INCINERATION IN SWITZERLAND

- Production of MSW: ca. 3.1Mt/yr<sup>d</sup>
- Incineration capacity: ca. 2.9Mt/yr<sup>e</sup> (in 1996)
- Incineration of MSW: ca. 2.3Mt/yr<sup>f</sup> (in 1996)

By the year 2000, 100% of MSW will have to be incinerated. Therefore, calculations in this document are based on **3.1Mt/yr of MSW<sup>g</sup>**.

### • RESIDUES OF INCINERATION

The actual mass transfer coefficients between MSW and incineration residues (BA=bottom ash; FA=fly ash; FC=filter cake) are<sup>h</sup>:

- MSW→BA: 25%
- MSW→FA: 1.5%
- MSW→FC: 0.375%

The amount of residues produced on the basis of 3.1Mt/yr of MSW would thus be **775kt/yr of BA, 46.5kt/yr of FA, and 11.6kt/yr of FC.**

(a) The term "MSW glass" applies here to glassy, inert or partly/completely crystallised material that is produced by vitrification or inertisation in alternative processes operated at high temperature.

(b) In-line process: alternative process producing MSW glass from the direct vitrification or inertisation of MSW.

(c) Post-process: alternative process producing MSW glass from the vitrification or inertisation of residues of MSW incineration (bottom ash, fly ash, filter cake).

(d) D. Chambaz, BUWAL; personal communication.

(e) BUWAL (1998). L'usine d'incinération propre: mythe ou réalité? Cahier de l'Environnement 299.

(f) *Ibid.*

(g) This hypothesis is conservative, as the actual trend in Switzerland is towards a net increase of non-incinerated/selectively collected wastes (Le Temps, January 19, 1999).

(h) BUWAL (1998). Die Rückstände der Verbrennung, Flugasche und Filterkuchen. Umwelt-Materialien 100.

BUWAL (1998). L'usine d'incinération propre: mythe ou réalité? Cahier de l'Environnement 299.

- **ALTERNATIVE VITRIFICATION/INERTISATION PROCESSES**

The chosen scenario implies that the 28 existing swiss MSW incineration plants would be replaced by in-line processes, or updated with post-processes<sup>a</sup>. The list of alternative processes that could be implemented in Switzerland is large<sup>b</sup>, but a limited number of processes were selected for the present approach; their input and output characteristics are given in the table below:

Table 1

Process type	Process name	Process input <sup>c</sup>	Input→output <sup>d</sup>	Process output <sup>e</sup>
in-line process	Küpat VS	MSW=3.1Mt/yr	18.7% <sup>f</sup>	579.7kt/yr
	Siemens SBV	MSW=3.1Mt/yr	14.0% <sup>g</sup>	434.0kt/yr
	Thermoselect	MSW=3.1Mt/yr	23.0% <sup>h</sup>	713.0kt/yr
	Von Roll RCP	MSW=3.1Mt/yr	20.5% <sup>i</sup>	635.5kt/yr
post-process	Von Roll HSR	BA=775kt/yr	88.9% <sup>j</sup>	689.0kt/yr
	ABB InRec	BA(fine fraction <sup>k</sup> )=248kt/yr + FA=46.5kt/yr	70.4%	207.3kt/yr
	ABB AshArc	FA=46.5kt/yr	70.4%	32.7kt/yr
	ABB Deglor	FA=46.5kt/yr	75.0%	34.9kt/yr
	CTU Fluapur	FA=46.5kt/yr	74.0% <sup>l</sup>	34.5kt/yr
	Kubota KSMF	FA=46.5kt/yr	82.5%	38.4kt/yr
	Seiler SHT	FA=46.5kt/yr	72.5%	33.7kt/yr
	MGC Plasmox	FA=46.5kt/yr + FC=11.6kt/yr	82.0%	47.7kt/yr
	Steinmüller EloMelt	FA=46.5kt/yr + FC=11.6kt/yr	90.3%	52.5kt/yr

Thus, the estimated total mass of vitrified or inertised material that would be produced under the conditions of the scenario is:

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- (a) This scenario is conservative, as the total pool of swiss MSW incineration plants would be replaced in around 25-30yr.
  - (b) Some of the processes selected for the present approach are described in details in: BUWAL (1998). Die Rückstände der Verbrennung, Flugasche und Filterkuchen. Umwelt-Materialien 100. Some other processes are also available but not considered here; they will be discussed in details in report 4 (Long-term stability of MSW glasses; Autumn 1999).
  - (c) The column "Process input" indicates the estimated masses of MSW (in-line processes) or BA, FA, FC (post-processes) that would be vitrified/inertised by the alternative processes in the case of the present scenario.
  - (d) The column "Input→output" indicates the mass transfer coefficient between the input of the process and the final MSW glass; if not specified, this coefficient is tabulated in: BUWAL (1998). Die Rückstände der Verbrennung, Flugasche und Filterkuchen. Umwelt-Materialien 100.
  - (e) The column "Process output" indicates the estimated mass of vitrified/inertised material that would be produced in the present scenario.
  - (f) Küpat (1996). Untersuchungen zum VS-Verfahren im Dauerbetrieb; Zusammenfassung Abschlussbericht.
  - (g) Siemens (1994). Die Schwel-Brenn-Anlage, eine Verfahrensbeschreibung.
  - (h) Hässler G. (1995). Thermoselect. Verlag Karl Goerner, Karlsruhe, Germany.
  - (i) Von Roll (1996). RCP-Verfahren, Standard-Angebot.
  - (j) ARGE HSR (1996). Thermische Behandlung von Rückständen aus Kehrichtverbrennungsanlagen nach dem HSR-Verfahren. Zusammenfassender Schlussbericht über die Pilotversuche.
  - (k) The InRec process treats the fine fraction of the bottom ash; the mass transfer coefficient between MSW and this fraction is  $MSW \rightarrow BA_{\text{fine}}$ : 8%, according to the manufacturer of the process.
  - (l) For CTU Fluapur, input→output is arbitrarily calculated as the average between the mass transfer coefficients of AshArc, Deglor, KSMF, SHT and HSR.

- ca. 400-700kt/yr for in-line processes
- ca. 200-700kt/yr for post-processes based on bottom ash
- ca. 30-50kt/yr for post-processes based on fly ash

If one considers that the output material of these processes is glass<sup>a</sup>, its estimated total volume is thus:

- ca. 200-350·10<sup>3</sup>m<sup>3</sup>/yr for in-line processes
- ca. 100-350·10<sup>3</sup>m<sup>3</sup>/yr for post-processes based on bottom ash
- ca. 15-25·10<sup>3</sup>m<sup>3</sup>/yr for post-processes based on fly ash

## TOXIC ELEMENTS

The estimation of the content and total mass of toxic elements in the postulated MSW glasses is based on a general survey driven by BUWAL on the operating of alternative processes under comparable conditions<sup>b</sup>. In that survey, the following toxic elements were analysed: Cd, Cr, Cu, Hg, Pb, Zn. The present approach will exclusively consider these elements.

Roughly, the estimated content of toxic elements in the MSW glasses produced by each selected alternative process is calculated as follows:

- (1) Estimation of the content of toxics in the input material (MSW, BA, FA, FC), using different sources<sup>c</sup>
- (2) Estimation of the content of toxics in the MSW glasses, using mostly input→output elemental transfer coefficients<sup>d</sup>
- (3) Estimation of the total mass of toxics in the MSW glasses, using mostly input→output mass transfer coefficients

Table 2

Process name	Cadmium		Chromium		Copper		Mercury		Lead		Zinc	
	mg/kg	kg/yr	mg/kg	t/yr	mg/kg	t/yr	mg/kg	kg/yr	mg/kg	t/yr	mg/kg	t/yr
VS	0.3 <sup>e</sup>	174	221	128	8877	5146	-	-	187	108	973	564
SBV	4.0	1736	980	425	1900	825	1.00	434	800	347	2000	868
Thermosel.	0.5	357	2700	1925	1700	1212	0.70	499	500	357	400	285
RCP	0.5	318	2000	1271	400	254	0.10	64	75	48	400	254
HSR	0.03	24	674	465	558	384	0.02	13	58	40	345	238
InRec	4.0	829	-	-	500	104	-	-	100	21	700	145
AshArc	4.4	144	142	4.6	512	17	0.07	2	106	3.5	345	11
Deglor	4.2	147	667	23	587	21	0.07	2	796	28	16178	564
Fluapur	1.6	55	-	-	14	0.5	-	-	29	1.0	916	32
KSMF	37.8	1450	480	18	970	37	0.06	2	1810	69	8824	339
SHT	4.3	145	441	15	1103	37	0.07	2	412	14	8033	271
Plasmox	5.7	272	4.4	0.2	52	2.5	-	-	225	11	443	21
EloMelt	0.6	32	371	20	591	31	0.75	39	314	17	893	47

(a) Density of glass: 2.6g/cm<sup>3</sup>; apparent density of crushed/uncompacted glass: 2g/cm<sup>3</sup>. Colombel P. (1996). Etude du comportement à long terme de vitrifiés de REFIOM. PhD dissertation, University of Poitiers, France.

(b) All details of the survey are given in: BUWAL (1998). Die Rückstände der Verbrennung, Flugasche und Filterkuchen. Umwelt-Materialien 100.

(c) [toxics]<sub>MSW</sub> is calculated from: BUWAL (1993, 1997), Umwelt in der Schweiz. Schenk K., Chambaz D. (BUWAL), personal communications.

[toxics]<sub>BA,FA,FC</sub> is extracted from: BUWAL (1998). Die Rückstände der Verbrennung, Flugasche und Filterkuchen. Umwelt-Materialien 100. Schenk K., Chambaz D. (BUWAL), personal communications.

(d) Chambaz D. (BUWAL), personal communication.

(e) Concentrations and masses indicated in this table are rounded to the nearest value.

According to table 2, MSW glasses can be classified as a function of their content of toxic elements:

- **[Cd]:** HSR << VS = Thermoselect = RCP = EloMelt < Fluapur < SBV = InRec = Deglor = SHT = AshArc < Plasmox << KSMF
- **[Cr]:** = Plasmox << AshArc < VS < EloMelt < SHT = KSMF < Deglor = HSR << SBV << RCP < Thermoselect
- **[Cu]:** Fluapur < Plasmox << RCP < InRec = AshArc < HSR = Deglor = EloMelt << KSMF < SHT < Thermoselect < SBV << VS
- **[Hg]:** HSR < KSMF = AshArc = Deglor = SHT < RCP << Thermoselect = EloMelt < SBV
- **[Pb]:** Fluapur < HSR << RCP < InRec = AshArc < VS < Plasmox < EloMelt < SHT < Thermo < Deglor = SBV << KSMF
- **[Zn]:** AshArc = HSR = Thermoselect = RCP = Plasmox < InRec < EloMelt = Fluapur = VS << SBV << SHT = KSMF << Deglor

According to their toxics content, glasses RCP, HSR, InRec, AshArc, Fluapur, Plasmox, EloMelt would be below or right at the limit allowing disposal in landfills for inert material, as stated by the TVA/OTD<sup>a</sup>. This criteria does however not take into account the possible leachability of the glasses.

## ANALOG GLASS

The choice of a pertinent analog to the MSW glasses is intimately linked to the conditions addressing the proposed approach, *i.e.*:

- The analog must be prepared from MSW or their residues (BA, FA, FC), so as to contain similar amounts of toxic metals and major elements.
- The analog must be prepared at a temperature representative of the ones in the swiss alternative processes.
- The corrosion behaviour of the analog must be studied under conditions similar to the ones under which the MSW glasses should be exposed.

These requirements restrict the number of possible analogs. Nevertheless, several works report good candidates for our approach<sup>b</sup>. Amongst these, one of the **MSW glasses studied by Colombel** has been selected as the pertinent analog for our study. Some of its major characteristics are<sup>c</sup>:

- **Preparation:** vitrification of fly ash (no additives) at 1445°C (electric arc)
- **Major elements:** 33.7% SiO<sub>2</sub>, 35.0% CaO, 16.9% Al<sub>2</sub>O<sub>3</sub>, 3.6% MgO, 2.5% TiO<sub>2</sub>, 2.2% Fe<sub>2</sub>O<sub>3</sub>, 2.0% P<sub>2</sub>O<sub>5</sub>, 1.1% Na<sub>2</sub>O
- **Trace elements:** 2ppm Cd, 1574ppm Cr, 248ppm Cu, 149ppm Pb, 13015ppm Zn
- **Corrosion tests:** crushed granules with/without binder, subject to

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(a) See BUWAL (1996). Technische Verordnung über Abfälle (TVA), #814.015; Appendix 1, Point 11b.

(b) The work of three authors has been retained for their studies:

-Kipka A. (1995). Eigenschaften verglaster Flugaschen aus der Müllverbrennung-Einschmelzverhalten und Korrosion. Fortschr.-Ber. VDI Reihe 15, Nr. 141, VDI-Verlag, Düsseldorf, Germany (and related works).

-Sterpenich J. (1998). Altération des vitraux médiévaux, contribution à l'étude du comportement à long terme des verres de confinement. PhD dissertation, University Henri Poincaré, Nancy, France (and related works).

-Colombel P. (1996). Etude du comportement à long terme de vitrifiats de REFIOM. PhD dissertation, University of Poitiers, France (and related works).

(c) Report 4 (Long-term stability of MSW glasses; Autumn 1999) describes in details this analog glass and the corrosion tests applied to it.

corrosion under road conditions (leachants: H<sub>2</sub>O, saline H<sub>2</sub>O, alkaline H<sub>2</sub>O; low flow-rate, T<sub>room</sub>, t=200d); other corrossions were performed.

### • CORROSION BEHAVIOUR OF THE ANALOG GLASS

The MSW glass studied by Colombel under conservative<sup>a</sup> road conditions exhibits the following behaviour:

- Whatever the leachant chosen, the **normalised element losses and release rates are systematically much smaller than the ones for granite** under identical conditions.
- Whatever the conditions chosen, the **corrosion rate strongly slows down** after an initial period of alteration (ca. 1 month).
- Whatever the conditions chosen, an **elevated temperature does not systematically accelerate the corrosion** (90°C vs. 25°C).
- The presence of a **cement binder has a negative effect on corrosion**, as compared to MSW glass granules only.
- **Strongly alkaline conditions of leaching have an negative effect on corrosion**, as compared to leaching with H<sub>2</sub>O or saline-H<sub>2</sub>O.

Taking into account her working conditions, the corrosion data obtained by Colombel can be converted<sup>b</sup> into a conventional corrosion rate<sup>c</sup>, which, in a conservative case, must be representative of the maximum rate at which the MSW glass dissolves. **The proposed corrosion rate to be used for the present approach is<sup>d</sup>:**

- $v_{(Ca),analog} = 10^{-3}g/m^2 \cdot d$

### • CONVERTING ANALOG CORROSION TO MSW GLASS CORROSION

Knowing the conditions under which the MSW glasses would be exposed, the above mentioned corrosion rate can be used to estimate the mass of toxic elements that would be released over a given period of time. Indeed, this conversion is only feasible if:

- (1) the surface of the MSW glass exposed to leaching, and its proportion of toxic elements, are known<sup>e</sup>,
- (2) the corrosion scenarii for the analog and MSW glass are equivalent,
- (3) the toxic elements present in the MSW glass will be released at a

(a) Colombel considers that the asphalt overlying the different foundation layers is totally porous, i.e. 100% of water falling onto the road percolates through the layer of MSW glass granules.

(b) Details of the conversion from Colombel's results to corrosion rates will be given in report 4 (Long-term stability of MSW glasses; Autumn 1999).

(c) The corrosion rate  $v_{(i)}$  of the element (i) is expressed as  $v_{(i)} = NL_{(i)}/dt$ , [g/m<sup>2</sup>·d]. The **normalised element loss**  $NL_{(i)}$  of the element (i) is expressed as  $NL_{(i)} = ([C_{(i)}]_{solution} \cdot V_{solution}) / (\%_{(i)} \cdot S_{glass})$ , [g/m<sup>2</sup>];  $[C_{(i)}]_{solution}$  = concentration of the element (i) measured in the leachant [mg/cm<sup>3</sup>];  $V_{solution}$  = volume of the leachant [cm<sup>3</sup>],  $\%_{(i)}$  = initial proportion of the element (i) in the glass [mg/kg];  $S_{glass}$  = surface of the glass [m<sup>2</sup>].

(d) This rate was obtained after 200 days of leaching of a cylinder (h=20cm, Ø=10cm) containing 3kg of crushed/non-compacted granules (0-2cm) of analog MSW glass;  $S_{glass}$  is ca. 4m<sup>2</sup>. Leaching is processed with ultra-pure H<sub>2</sub>O (pH equilibrates freely to 7-8) at T=25°C and F=40ml/d. Under these conditions, the most mobile element is observed to be calcium, thus  $v_{(i)} = v_{(Ca)}$ .

(e) Conversion from the corrosion rate  $v_{(Ca),analog}$  to the loss of toxic elements (tox) from the MSW glasses during an interval  $\Delta t$  is obtained by  $m_{(tox)} = v_{(Ca),analog} \cdot \%_{(tox)} \cdot S_{glass} \cdot \Delta t$  [g];  $\%_{(tox)}$  = initial proportion of toxic element (tox) in the MSW glass;  $S_{glass}$  = surface of the MSW glass.

rate equal to or smaller than the chosen corrosion rate.

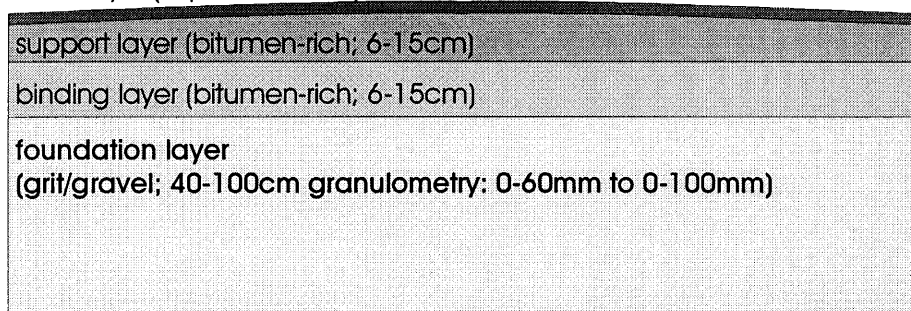
## SCENARIO

Although the proposed approach is questionable<sup>a</sup>, it is still pertinent to estimate the loss of toxic elements from the MSW glasses under given conditions of reuse. Indeed, the mere comparison of their toxics content does not inform on their extent of release in regard to natural and anthropogenic fluxes of toxics<sup>b</sup>. The retained scenario is:

- The MSW glasses are reused as **foundation layers in road construction**.
  - These roads are **exposed to rain**, able to leach the foundation layers.
  - During leaching, **toxics are released and lost in the environment** without possibility of drainage and post-treatment or scavenging.
- **THE HYPOTHETICAL "GLASS ROAD"**<sup>c</sup>

There is no "universal" road in Switzerland. However, the following parameters may apply for the sake of our approach (see the figure):

wear layer (asphalt; 3-4cm)



- The permeability<sup>d</sup> of the wear layer is usually around 4-5%, but may reach up to 20-30% in the case of draining asphalt used on highways. In our scenario, **permeability = 30%** is chosen as a detrimental case.
- Usually, the foundation layer is made up of raw grit/gravel, but it may occasionally (ca. 20% of the cases) contain cement as binder. In our scenario, it is assumed that **raw, crushed, uncompacted MSW glass** is used as a surrogate of raw grit/gravel.
- The foundation layer may reach 100cm thick. In our scenario, and in agreement with the TVA/OTD<sup>e</sup>, **thickness = 50cm for MSW glass**.
- It is assumed that the MSW glasses used as foundation layer will have a

(a) Amongst criticisms is the fact that every single MSW material behaves its own way, as a function of its mode of preparation and composition (e.g. CTU Fluapur is not glassy); it is thus not realistic to use the corrosion rate of the analog ( $V_{(Ca, analog)}$ ) as a simple conversion factor. Nevertheless, the approach is expected to give orders of magnitude rather than accurate results.

(b) For example, the fact that some of the MSW glasses considered in this study could be disposed of in landfills for inert material on the basis of their content in toxics does not imply necessarily that they could be reused in the everyday life.

(c) Informations in this section mostly originate from a discussion with T. Bühler, Colas S.A., who is kindly acknowledged. An accurate description of the technique of road construction, including the technical norms, is available by the VSS, Vereinigung Schweizerischer Strassenfachleute, Zürich.

(d) Permeability: the ratio of water flowing through the wear layer to water reaching the wear layer.

(e) Bottom ash may be used in the foundation layer (up to 50cm thickness), provided it fulfills the requirements of the TVA/OTD, Article 13.2.b.

**uniform granulometry of 1 cm<sup>a</sup>.**

- One considers rain precipitations of 1500mm/yr<sup>b</sup>. Taking into account a permeability of 30%, rain percolating through the MSW glass layer re-sumes to **flow-rates of 50ml/h·m<sup>2</sup>** (continuous rain) to **200ml/h·m<sup>2</sup>** (discontinuous rain)<sup>c</sup>. For maximum security, the latter is considered as a permanent flow-rate<sup>d</sup>.
- The model road that is built in our scenario has a **width of 10m<sup>e</sup>**.

In conclusion, one may consider the following starting conditions for estimating the corrosion of the MSW glasses used in road construction:

**Table 3**

Vitrification/inertisation process	MSW glass granules produced (Ø=1 cm)			Road built with MSW glass	
	mass [kt/yr]	volume [m <sup>3</sup> /yr]	surface [m <sup>2</sup> /yr]	length [km/yr]	surface [m <sup>2</sup> /yr]
in-line process	400-700	200-350·10 <sup>3</sup>	10-17·10 <sup>7</sup>	40-70	40-70·10 <sup>4</sup>
post-process (based on BA)	200-700	100-350·10 <sup>3</sup>	5-16·10 <sup>7</sup>	20-70	20-70·10 <sup>4</sup>
post-process (based on FA)	30-50	15-25·10 <sup>3</sup>	0.75-1.2·10 <sup>7</sup>	3-5	3-5·10 <sup>4</sup>

**CORROSION**

The corrosion of the MSW glass granules during the above mentioned penalising conditions<sup>f</sup> of reuse in road conditions can be estimated on an annual scale and on the scale of the life-time of the MSW glass.

• **BULK DISSOLUTION OF GLASS**

If one considers, as a conservative approach, that the release rate of the most mobile element, Ca, in the analog MSW glass is directly representative of the dissolution rate of the bulk of the glass, and that this rate can be directly applied to the MSW glass granules considered in our approach (i.e.  $v_{(Ca),analog} = 10^{-3}g/m^2 \cdot d = v_{analog\ glass} = v_{MSW\ glass}$ ), then:

**Table 4**

Vitrification/inertisation process	Annual glass production	Annual glass corrosion	Life-time of MSW glass [yr]
	mass [kt/yr]	mass [t/yr]	
in-line process	400-700	37-60	1.2·10 <sup>4</sup>
post-process (based on BA)	200	18-60	
post-process (based on FA)	30-50	3-4.5	

Thus, if one considers Colombel's rate constant as a pertinent corrosion

- 
- (a) This value is the mean of the granulometry considered in Colombel's work. For spherical granules, their volume is thus  $V_{granule}=0.53cm^3$ , and their surface area is  $S_{granule}=3.14cm^2$ , slightly underestimated as compared to Colombel.
  - (b) An average of 1500mm/yr represents a continuous flow-rate of 170ml/h·m<sup>2</sup>, or a discontinuous flow-rate of 680ml/h·m<sup>2</sup> (1 day rain every 4 days). Precipitations in Switzerland range between >500mm/yr (Alps, Valais) and <4000mm/yr (Alps, Bern), with averages of 1000-1200mm/yr on the Jura and 1500-2000mm/yr on the Plateau. Météo Suisse, personal communication.
  - (c) These flow-rates are in agreement with Colombel, who considers a continuous flow-rate  $F=40ml/d$ , i.e. 212ml/h·m<sup>2</sup>.
  - (d) 200ml/h·m<sup>2</sup> continuous flow-rate corresponds to precipitations of 6000mm/yr.
  - (e) For a width of 10m and a thickness of 50cm of MSW glass as foundation layer, 1km of road would thus require 5·10<sup>3</sup>m<sup>3</sup> of crushed/non-compacted MSW glass granules.
  - (f) Penalising conditions have been considered at every step of the scenario: highest permeability of the road (30%), small size of MSW glass granules (Ø=1 cm), corrosion rate extrapolated from the most mobile element (Ca), higher boundaries for the rain precipitation (200ml/h·m<sup>2</sup> in continuous).

rate which can be indistinctly applied to our MSW glasses, **the estimated time-life of MSW glass granules is ca. 10<sup>4</sup> years**, under highly conservative conditions.

● **LOSS OF TOXIC ELEMENTS DURING LEACHING**

The estimated annual corrosion of MSW glass can be converted into annual losses of toxic elements<sup>a</sup>. In addition, these annual elemental losses can be converted into concentrations of toxics that will be released into the leaching water<sup>b</sup>. These results, given in the table below, represent the maximum possible estimates.

Table 5

Vitrification/inertisation process	Glass produced [kt/yr]	Road surface [m <sup>2</sup> /yr]	Element	Annual loss <sup>c</sup> [kg/yr]	[element] <sub>leachant</sub> <sup>d</sup> [µg/l]
in-line process	400-700	40-70·10 <sup>4</sup>	Cd	0.02-0.15	<0.8
			Cr	10-160	<500
			Cu	20-430	<1700
			Hg	<0.01-0.04	<0.2
			Pb	4-30	<150
			Zn	20-75	<400
post-process (based on BA)	200-700	20-70·10 <sup>4</sup>	Cd	<0.01-0.07	<0.8
			Cr	40	<150
			Cu	9-32	<100
			Hg	<0.01	<0.01
			Pb	1.8-3.4	<20
			Zn	12-20	<150
post-process (based on FA)	30-50	3-5·10 <sup>4</sup>	Cd	<0.01-0.12	<7
			Cr	<0.02-2	<150
			Cu	0.04-3	<200
			Hg	<0.01	<0.2
			Pb	0.08-6	<350
			Zn	1-50	<3000

At a first glance, and although some of the MSW glasses presented in ta-

- (a) The conversion "annual dissolution of glass" → "annual loss of toxics" takes into account the initial concentrations of toxics in the glasses (see table 2).
- (b) The conversion "annual loss of toxics" → "concentrations of leached toxics" takes into account the minimal (penalising) volume of rain precipitations percolating through the road (30% permeability): for rain precipitations of 1500mm/yr, a volume of 0.45m<sup>3</sup>/yr of rain percolates through 1m<sup>2</sup> of road.
- (c) The minimum and maximum concentrations of these elements in the MSW glasses of the given process (e.g., Cu in MSW glasses produced by post-processes based of fly ash ranges between 14 and 1103mg/kg; see table 2), together with the minimum and maximum mass losses of glasses produced by the given process (e.g. 3-4.5t/yr of glass produced by post-processes based on fly ash; see table 4), have been considered for the calculation of the annual losses of toxic elements. Results are rounded to the nearest value.
- (d) As a conservative approach, and due to the very small amounts of toxics losses, only the maximum losses of elements through the MSW glass layer have been considered to calculate the maximum concentrations of toxics.

bles 1 and 2 would not be admitted in landfills for inert material because of their high nominal content in toxic metals, the pessimistic, penalising and over-conservative approach adopted in our scenario clearly shows that:

- (1) The MSW glasses are highly stable under conditions of reuse in road construction: their **estimated life-time is around 10<sup>4</sup>yr.**
- (2) The dissolution of the MSW glasses results in small amounts of released toxics in their close environment: the **total loss of toxics is between 2 and 500kg/yr**, copper being responsible for the dominant fraction of this loss.
- (3) The transfer of toxics from the MSW glasses to the aqueous leaching phase results in negligible concentrations of toxics in the output reservoir: the **maximum concentration of toxics in percolating waters is smaller than 5mg/l**, occasionally around 0.1 mg/l, and in most instances much below 0.1 mg/l.

## OTHER FLUXES

To test the potential risk or reuse of MSW glasses in road construction, some natural and anthropogenic fluxes and concentrations of toxics in some pertinent reservoirs of the environment have been taken into account. These various fluxes and concentrations are:

- toxics in **rain precipitations**,
- toxics in **atmospheric depositions**,
- toxics in **rocks, soils, rivers and oceans**,
- toxics in **clinker, cement and concrete**,
- **mass-balance of cadmium and copper** in some environmental reservoirs in Switzerland.

Data presented in the next table are in most cases rough estimates (minima, maxima or median) of concentrations and fluxes of the considered toxic metals (notice the different units). Except in specific situations, data are representative of averages, and are a compilation of different bibliographic sources<sup>a</sup>. For most reservoirs and elements, the variability is apparently considerable.

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(a) Relevant data are extracted from the following sources:

- Reimann C., de Caritat P. (1998). Chemical Elements in the Environment, Factsheets for the Geochemist and Environmental Scientist. Springer, Berlin, Germany.
- Drever J.I. (1982). The geochemistry of natural waters. Prentice-Hall, New Jersey, U.S.A.
- BUWAL (1998). Kupfer in der Schweiz, Standortbestimmung. In Vorbereitung.
- BUWAL (1997). Abfallentsorgung in Zementwerken. Umweltmaterialien Nr. 70.
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- BUWAL (1996). Hydrologisches Jahrbuch des Schweiz.
- Strahm E., Deillon F., Jacobs F. (1997). Schwermetallgehalte in Zementklinkern aus schweizerischen Zementwerken. TFB Bericht Nr. 969002. Technische Forschungs- und Beratungsstelle des Schweizerischen Zementindustrie. Wildegg.
- VDZ (1996). Beton. Verein Deutscher Zementwerke. Zusammenfassung des Tätigkeitsberichtes des Forschungsinstituts der Zementindustrie '93-'96, und der Sachstandberichte der VDZ/BDZ Kommission. Düsseldorf, Germany
- Krauskopf K.B., Bird D.K. (1995). Introduction to Geochemistry. McGraw-Hill, New York, U.S.A..
- Chambaz D., Schenk K. (BUWAL), personal communications.
- Pfeiffer H.-R. (University of Lausanne), personal communication.

Table 6

	Cd	Cr	Cu	Hg	Pb	Zn
upper continental crust (min-max) [ $\mu\text{g}/\text{kg}$ ]	30 - 300	$4 \cdot 10^3$ - $2.98 \cdot 10^6$	$4 \cdot 10^3$ - $8.7 \cdot 10^4$	4 - 400	$10^3$ - $2 \cdot 10^4$	$1.6 \cdot 10^4$ - $1.3 \cdot 10^5$
oceanic crust (ocean ridge basalt) (median) [ $\mu\text{g}/\text{kg}$ ]	100 - 130	$2.7 \cdot 10^5$ - $3.17 \cdot 10^5$	$8 \cdot 10^4$ - $8.6 \cdot 10^4$	10 - 20	800 - $10^3$	$7 \cdot 10^4$ - $8.5 \cdot 10^4$
average world soil (median) [ $\mu\text{g}/\text{kg}$ ]	300	$8 \cdot 10^4$	$2.5 \cdot 10^4$	50	$1.7 \cdot 10^4$	$7 \cdot 10^4$
typical urban soil (min-max) [ $\mu\text{g}/\text{kg}$ ]	10 - $1.13 \cdot 10^4$	$7.9 \cdot 10^3$ - $1.99 \cdot 10^5$	$1.7 \cdot 10^3$ - $7.06 \cdot 10^5$	20 - $4.49 \cdot 10^3$	$9 \cdot 10^3$ - $9.76 \cdot 10^5$	$7.4 \cdot 10^3$ - $3.42 \cdot 10^6$
basaltic and gabbroic rocks (median) [ $\mu\text{g}/\text{kg}$ ]	100 - 210	$1.14 \cdot 10^5$ - $1.85 \cdot 10^5$	$8.7 \cdot 10^4$ - $1.1 \cdot 10^5$	10 - 200	$3.5 \cdot 10^3$ - $7.8 \cdot 10^3$	$8.6 \cdot 10^4$ - $1.18 \cdot 10^5$
granite (median) [ $\mu\text{g}/\text{kg}$ ]	30 - 130	$4 \cdot 10^3$ - $2.2 \cdot 10^4$	$10^3$ - $3 \cdot 10^4$	30 - 100	$1.5 \cdot 10^4$ - $4.8 \cdot 10^4$	$3.9 \cdot 10^4$ - $6 \cdot 10^4$
rain and snow precipitation (min-max) [ $\mu\text{g}/\text{l}$ ]	0.01 - 5.1	0.1 - 2.7	0.01 - $2.19 \cdot 10^3$	-	0.1 - 42	0.02 - 197
average world stream water (median) [ $\mu\text{g}/\text{l}$ ]	0.02	0.7 - 1	3 - 7	0.05 - 0.07	1 - 3	15 - 30
Rhine river (CH-outlet in Weil) (min-max 1996) [ $\mu\text{g}/\text{l}$ ]	-	-	1 - 3.6	-	0.2 - 2.1	3 - 9
Rhône river (pre-Geneva Lake) (min-max 1996-1997) [ $\mu\text{g}/\text{l}$ ]	0.01 - 0.14	0.6 - 9.1	0.7 - 11.7	<0.05	0.5 - 12.6	3 - 57
average world ocean water (median) [ $\mu\text{g}/\text{l}$ ]	0.05 - 0.1	0.2 - 0.3	0.1 - 0.5	0.0004 - 0.03	0.003 - 0.03	0.3 - 4.9
swiss clinker (min, max) [ $\mu\text{g}/\text{kg}$ ]	10 - $1.5 \cdot 10^3$	$1.1 \cdot 10^4$ - $3.19 \cdot 10^5$	$5 \cdot 10^3$ - $1.36 \cdot 10^5$	<10 - $1.2 \cdot 10^3$	$10^3$ - $1.12 \cdot 10^5$	$2.9 \cdot 10^4$ - $5.31 \cdot 10^5$
swiss clinker (max allowed) [ $\mu\text{g}/\text{kg}$ ]	$1.5 \cdot 10^3$	$1.5 \cdot 10^5$	$10^5$	-	$10^5$	$3.5 \cdot 10^5$
swiss Portland cement (max allowed) [ $\mu\text{g}/\text{kg}$ ]	$1.5 \cdot 10^3$	-	-	500	-	-
german Portland cement (max) [ $\mu\text{g}/\text{kg}$ ]	$6 \cdot 10^3$	$1.3 \cdot 10^5$	$2.2 \cdot 10^4$	200	$2.6 \cdot 10^5$	$6.8 \cdot 10^5$
MSW glass additive for cement <sup>a</sup> (max allowed) [ $\mu\text{g}/\text{kg}$ ]	$10^3$	$2 \cdot 10^6$	$6 \cdot 10^5$	500	$7.5 \cdot 10^4$	$4 \cdot 10^5$
german concrete (max) [ $\mu\text{g}/\text{kg}$ ]	$3 \cdot 10^3$	$10^5$	-	200	$10^5$	$2 \cdot 10^5$
typical atmospheric deposition (min-max) [ $\text{mg}/\text{m}^2 \cdot \text{yr}$ ]	0.05 - 2	0.6 - 5.24	0.9 - 494	-	0.6 - 35.3	10 - 300
loss from roofs and roofgutters (min-max) [ $\text{mg}/\text{m}^2 \cdot \text{yr}$ ]	-	-	$6 \cdot 10^3$ - $1.9 \cdot 10^4$	-	-	-
net input in environmental reservoir (Switzerland, 1990) [t/yr]	7.8 lithos. 2.1 hydros. 31.5 landfills	-	<125 hydros <90 waste- water sludge	-	-	-

## COMPARISON

In order to compare the estimated contents of toxic elements in MSW glasses (see table 2 on page 3) and their losses from MSW glasses (see table 5 on page 8), and the natural/anthropogenic fluxes and concentrations of toxic elements (see table above), the following simplified assumptions have been made:

- **Comparison of the static pictures:** the minimal and maximal estimated concentrations of toxic elements in the MSW glasses produced by the in-line processes and post-processes, irrespective of the specific

(a) BUWAL (1998). Elimination des déchets dans les cimenteries; directive. It is possible to add inertised material produced by high-temperature alternative processes (*i.e.* MSW glasses) to the clinker during the preparation of swiss Portland cement, provided that it fulfills the requirements of the regulation.

process (see table 2 on page 3), are compared to the minimal and maximal concentrations of these elements in solid material from natural sources (earth crust, soils and rocks; see the rows 2 to 7 of table 6 on page 10), and from anthropogenic sources (clinker, cement, concrete; see the row 13, 16 and 18, of table 6 on page 10), irrespective of the specific material.

- **Comparison of the dynamic pictures:** the estimated concentrations of toxic elements released from leached MSW glasses into percolating water (see column 6 of table 5 on page 8) are compared to the concentrations of toxic elements in running waters (rain, snow, rivers; see the rows 8 to 11 of table 6 on page 10); in addition, the estimated annual amounts of toxic elements released from leached MSW glasses (see column 7 of table 5 on page 8) are compared to the calculated<sup>a</sup> annual amounts of toxic elements generated by natural and anthropogenic fluxes (rain and snow precipitation, atmospheric depositions, losses of Cu from roofs and roofgutters; see the rows 8, 19 and 20 of table 6 on page 10).

Table 7

Static picture of MSW glasses: concentrations of toxic elements						
	Cd [mg/kg]	Cr [mg/kg]	Cu [mg/kg]	Hg [mg/kg]	Pb [mg/kg]	Zn [mg/kg]
in-line processes <sup>b</sup>	0.3 - 4	221 - 2700	400 - 8877	0.1 - 1	75 - 800	400 - 2000
post-processes based on BA <sup>c</sup>	0.04-4	674	500-558	0.02	58-100	345-700
post-processes based on FA <sup>d</sup>	0.6 - 37.8	4.4 - 667	14 - 1103	0.06 - 0.75	29 - 1810	345 - 16178
natural solid material <sup>e</sup>	0.01 - 11.3	4 - 2980	1 - 706	0.004 - 4.49	0.8 - 976	7.4 - 3420
anthropogenic solid material <sup>f</sup>	0.01 - 6	11 - 319	5 - 136	<0.01 - 1.2	1 - 260	29 - 680

From the above mentioned table, it is difficult to give straight conclusions on the comparative content of toxic elements in MSW glasses and natural or anthropogenic solid materials. In fact, the ranges of concentrations in each of the process type or reservoir are too large.

It is however possible to extract approximate trends out of these data:

- **The minimal concentration of toxics observed in natural and anthropogenic materials is systematically smaller than for MSW glasses.**
- **The maximal concentration of toxics estimated in MSW glasses is not systematically larger than for natural and anthropogenic materials.**

A more refined approach would require the comparison of individual pro-

(a) Calculations are weighted to equivalent volumes of waters, *i.e.* normalised to the volume of water leaching MSW glasses at a permanent flow-rate of 200ml/h·m<sup>2</sup> (maximal leaching conditions, see page 7); of course, the postulated surface of road that can be built with MSW glasses originating from either in-line processes or post-processes is taken into account.

(b) In-line processes: VS, SBV, Thermoselect, RCP.

(c) Post-processes based on bottom ash (BA): HSR, InRec.

(d) Post-processes based on fly ash (FA): AshArc, Deglor, Fluapur, KSMF, SHT, Plasmox, Elomelt.

(e) Natural solid material: upper continental crust, oceanic crust, average world soil, typical urban soil, basaltic and gabbroic rocks, granite.

(f) Anthropogenic solid material: swiss clinker, german Portland cement, german concrete; the maximum allowed concentrations, being based on regulations, are not considered for the comparison.

cess types and individual solid materials. As the goal of this report is to discuss rough pictures rather than to designate "winner and loser" MSW glasses, the refined approach has thus not been adopted.

Table 8

Dynamic picture of MSW glasses: concentrations of released toxic elements						
	Cd [µg/l]	Cr [µg/l]	Cu [µg/l]	Hg [µg/l]	Pb [µg/l]	Zn [µg/l]
in-line processes	<0.8	<500	<1700	<0.2	<150	<400
post-processes based on BA	<0.8	<150	<100	<0.01	<20	<150
post-processes based on FA	<7	<150	<200	<0.2	<350	<3000
natural running waters <sup>a</sup>	0.01 - 5.1	0.1 - 9.1	0.01-2.19·10 <sup>3</sup>	<0.07	0.1 - 42	0.02 - 197

As for the static picture of MSW glasses, the ranges of concentrations of toxic elements are too large to allow for a straight comparison. However, data originating from rain and snow precipitation are apparently biased by the high concentration values which are representative of polluted areas. Consequently, it is possible to extract the following approximate trends:

- The release of cadmium from MSW glasses are in the lower range of the values in natural, unpolluted running waters.
- The releases of chromium, mercury, lead and zinc from MSW glasses are in the upper limits of, or higher than the average values in natural, unpolluted running waters.
- The release of copper from MSW glasses is close to the average values in natural, unpolluted running waters.

Table 9

Dynamic picture of MSW glasses: annual amounts of released toxic elements						
	Cd [kg/yr]	Cr [kg/yr]	Cu [kg/yr]	Hg [kg/yr]	Pb [kg/yr]	Zn [kg/yr]
in-line processes	0.02 - 0.15	10 - 160	20 - 430	<0.01 - 0.04	4 - 30	20 - 75
post-processes based on BA	<0.01 - 0.07	40	9 - 32	<0.01	1.8 - 3.4	12 - 20
post-processes based on FA	<0.01 - 0.12	<0.02 - 2	0.04 - 3	<0.01	0.08 - 6	1 - 50
natural/anthropogenic fluxes <sup>b</sup> :						
-40-70km road/in-line process	0.01 - 5.4	0.06 - 3.7	0.01 - 10 <sup>4</sup>	-	0.06 - 44	0.012 - 210
-20-70km road/post-proc. BA	0.005 - 5.4	0.03 - 3.7	0.005 - 10 <sup>4</sup>	-	0.03 - 44	0.006 - 210
-3-5km road/post-proc. FA	0.0005 - 0.4	0.005 - 0.3	0.0005 - 950	-	0.005 - 3.2	0.001 - 15

The values calculated for the natural and anthropogenic fluxes are highly spread. For cadmium, chromium and lead, these minimum and maxi-

- Natural running waters: rain and snow precipitation, average world stream water, Rhine river, Rhône river.
- Natural and anthropogenic fluxes: rain and snow precipitation, typical atmospheric deposition, loss of Cu from roofs and roofgutters. For rain and snow precipitation, the average swiss rain precipitation of 1500mm/yr (see page 7) is considered, *i.e.* a volume of 1.5m<sup>3</sup>/yr reaches 1m<sup>2</sup>. For atmospheric deposition, one considers the annual depositions on a surface equivalent to the surface of the road that can be built with MSW glasses. For loss of Cu from roofs and roofgutters, one considers roofs having a surface equivalent to the surface of the road that can be built with MSW glasses. Annual amounts of toxic metals generated by these natural and anthropogenic fluxes are calculated as the range between Flow<sub>minimum</sub>·S<sub>minimum</sub> and Flow<sub>maximum</sub>·S<sub>maximum</sub>, irrespective of the specific flux.

imum values are dominated by rain and snow precipitation; for copper and zinc, the minimum values are governed by rain/snow precipitation, but the maximum values are controlled by losses from roofs/roofgutters (copper), respectively by atmospheric deposition (zinc).

Although the variability of the calculated natural and anthropogenic fluxes is high, the following trends can be highlighted:

- Data for mercury cannot be compared, but the annual amount of this element released from MSW glasses is negligible.
- The annual amount of cadmium released from MSW glasses is in the low range of the values in natural and anthropogenic fluxes.
- The annual amounts of chromium, copper, lead and zinc released from MSW glasses are in the order of magnitude of the average values in natural and anthropogenic fluxes.
- Except for some situations, the maximum annual amounts of toxics released from MSW glasses are smaller than 100 kilograms/year.

## CONCLUSION

In order to assess the possible reuse of MSW glasses and inertised materials in civil engineering applications, a plausible scenario of reuse has been designed. This report proposes to compare, on the one hand, the theoretical contents of toxic metals in MSW glasses and the extent of possible toxic metal releases from these glass, and, on the other hand, the contents of toxic metals in natural and anthropogenic reservoirs and their respective fluxes.

The proposed scenario involves a series of assumptions, which have been addressed in the direction of a systematic overestimation of the concentrations and fluxes of toxics, and of the external conditions influencing the corrosion of MSW glasses. In that respect, the results can be considered as upper limits which could not be reached under more realistic conditions.

The step-by-step assumptions which have been applied throughout the proposed approach are summarised below:

- (1) All MSW incineration plants in Switzerland are replaced by alternative high-temperature vitrification/inertisation plants functioning either as in-line processes or post-processes.
- (2) The static characteristics of MSW glasses produced by individual alternative processes (*i.e.* their content of toxic elements) are realistically estimated from experimental work.
- (3) All MSW glasses produced by these alternative processes are exclusively reused as foundation layer for road construction. The hypothetical road is exposed to penalising conditions of alteration.
- (4) The corrosion of the MSW glass foundation layer is extracted from literature data obtained with an analog MSW glass. The corrosion rate is chosen as highly overestimated.
- (5) The dynamic characteristics of the hypothetical road (*i.e.* the release flux of toxics from MSW glasses) is conservatively estimated from the worst situations.
- (6) The static and dynamic pictures of MSW glasses are compared to realistic ranges of concentrations and fluxes of toxic metals in natural and anthropogenic reservoirs.

Taken as a whole, the proposed approach results in rough estimates of the maximum concentrations and fluxes of toxic metals in MSW glasses hypo-

thetically exposed to strongly penalising conditions of alteration. Several concentrations or fluxes are paradoxically very high; of course, these results may be biased by a single vitrification/inertisation process. Nevertheless, care has been taken to consider alternative processes collectively, rather than individually, because the objective of this preliminary report is not to classify these processes but simply to draw general trends.

The most salient results of the present work are:

- Examination of the static picture of MSW glasses (concentrations of toxic metals) does not inform on their degree of acceptance/rejection for landfill disposal, with regard to the actual swiss regulation.
- The estimated life-time of MSW glasses exposed to the proposed penalising conditions of alteration is exceptionally high.
- Comparison of the static picture of MSW glasses and natural or anthropogenic materials does not allow explicit conclusions. However MSW glasses are not systematically more contaminated than some other natural/anthropogenic materials encountered in our everyday life.
- For the dynamic picture of MSW glasses, the overestimated concentrations of released toxic elements are collectively in the order of magnitude of the concentrations determined in natural, unpolluted reservoirs.
- For the dynamic picture of MSW glasses, the overestimated quantities of released toxic elements are collectively in the order of magnitude of the quantities generated by natural and anthropogenic fluxes considered under identical conditions. In any situation, the total quantities of released toxics are fairly low.

To conclude, the present approach is promising, because it suggests that, although MSW glasses may contain important amounts of toxic metals, their stability could be large enough to induce negligible or minor loads of toxics in our close environment. Consequently, it is proposed that the present approach be retained for the evaluation of the long-term behaviour of MSW glasses (to be presented in report 4; Autumn 1999).

#### **CONCLUSION: SUMMARY**

A complete penalising scheme of corrosion of MSW glasses reused in road construction has been proposed. The estimated contents of toxic metals in MSW glasses, and their associated release fluxes, have been compared to contents and fluxes of these metals under natural and anthropogenic conditions. Although the present approach is questionable, it represents a pertinent scientific alternative within the frame of the revision of the TVA/OTD. The author suggests that this approach be taken into account as the scientific basis for the evaluation of the long-term behaviour of MSW glasses.