HAZARD CLASSIFICATION OF WASTE: REVIEW OF AVAILABLE PRACTICAL METHODS AND TOOLS

HENNEBERT P.*

** INERIS (National Institute for Industrial Environment and Risk Assessment), BP 33, F-13545 Aix-en-Provence Cedex 4, France, pierre.hennebert@ineris.fr*

SUMMARY: The different steps for classification are collection of information, use of the European list of waste, sampling, analysis, tests, hypothesis of speciation of elements into mineral substances, collecting hazard statement codes of substances, and comparing weighted sum or maxima of concentrations or tests results with given concentration limits for each hazard property, or eventual use of now available internet sites. Practical methods are proposed: tables for generic classification of elements, for "worst realistic case" speciation hypothesis, tests for HP 1, HP 2, HP 3, HP 12, HP 14, methods for HP 9 and HP 15.

1. INTRODUCTION

Hazard classification of waste is useful for the sound management and the recycling of potential resources. According to EU, the chemicals and waste policy areas are now converging, since the point is to minimise the adverse effects on human health and the environment, by phasing out hazardous chemicals or reducing release to air, water and soil. An exhaustive analysis of elements and substances and some tests are required to prove that a waste is non-hazardous. This can help to identify substances of concern not clearly evidenced by the waste management community. Many of these substances were legally used when the products were manufactured, but when the products become waste and are recovered, the now banned or restricted substance may still be contained in the recovered material. This classification can be used to improve the recycling of resources and to avoid dispersion of hazardous elements or substances during uncontrolled use (avoiding loops of hazardous substances). Some hard examples are plastics products with low concentration of antimony and brominated flame retardants from recycled plastics, concrete blocks with granulate of lead activated glass from cathode ray tubes, or dike reinforcement by sand and gravel from copper and lead slags.

The paper present practical methods and tests for waste classification. A focus is done on HP 14 'Ecotoxic', the most frequent hazard property.

2. LEGAL BACKGROUND, TECHNICAL GUIDANCE, GENERAL METHOD

Legal background can be found in EU (2014a, b), EU (2017a), and in national regulations. A European notice of technical guidance is available (EU 2018). UK and Nordic countries have proposed guidance documents (NRW et al. 2018, Norden 2015). To assess whether a waste is hazardous or not, the available data about the waste composition and properties must first be gathered, such as:

- knowledge of the waste and the process originating the waste;
- literature data;
- statistics of composition;
- waste analysis (analysis, physical tests, biotests).

The existing information on the waste can at best be sufficient to classify without performing complementary (analytical) work. Otherwise, it can guide the choices on the order and verification of the 15 hazard properties and the POP content.

A tiered assessment is recommended:

- 1st tier: Classification according to the European List of Waste (LoW) as “hazardous”, “non-hazardous”, or as “mirror entry”. In this latter case:
- 2nd tier: Some HP can be assessed as “hazardous” or “non-hazardous” by expert judgment;
- 3rd tier: The remaining HP can be assessed as “hazardous” or “non-hazardous” from organic content and “worst realistic case” hypothesis (see below) from total elemental content. If the “worst realistic case” approach is unsatisfactory (unrealistic, not in accordance with what is known of the waste), perform 4th tier;
- 4th tier: For some HP, perform specialized total analysis, leachate analysis or speciation of mineral content, or tests.

If the waste exhibits at least one hazard property among the 15 HP or exceed some POPs concentration, it is classified as hazardous. Conversely, to demonstrate that a waste is not hazardous, the 15 properties and POP concentration must be checked as non-hazardous. Typically, for suspected hazardous waste, cascading work is performed in an order depending of the waste and is stopped as soon as one property is verified as hazardous. And for suspected non-hazardous waste, a comprehensive study of the entire HP set is performed on. It is remembered that landfill acceptance criteria cannot replace the waste hazardousness assessment.

3. USE OF THE EUROPEAN LIST OF WASTE

The list (EU 2014a) has been refined with more precise definition of “absolute” entries (hazardous or not) and “mirror” entries (waste that can be hazardous or not depending on the concentration of hazardous substances) in EU (2018). If the waste fits in an “absolute entry”, the classification is done. Otherwise, sampling, analyses and/or tests must be performed to assess the 15 HPs and POPs concentration.

4. SAMPLING

Precise **sampling** plan requires the previous knowledge of the distribution of the elements or substances, ideally for each range of particle size. Standards for sampling plan calculations and sampling techniques are available (EN 14899, CEN/TR 15310-1 to -5). For waste of electrical and electronic equipment (WEEE), sampling plans are proposed for some fractions (CENELEC 2015). This cannot be developed here. Sampling delivers one or more **laboratory samples**.

5. ANALYSES AND TESTS

The second step is analysis. The **laboratory samples** must be pre-treated according to EN 15002. A standard method for determination of elements and organic substances in waste (with an analytical mass balance > 90% for solid waste and > 70% for liquid waste - not considering water) is practiced in France (AFNOR XP X30-489) and discussed at the CEN level (TC 444 'Environmental analyses of solid matrices'). Specific laboratory methods are needed for some peculiar analytes:

- Petroleum cuts (gasoline – i.e. CAS No 8006-61-9, gas oils/diesel – i.e. CAS No 68334-30-5, mineral oil – i.e. CAS No 64742-54-7) and creosote (CAS No 90640-85-0) should be identified as such (and not molecule by molecule) by the laboratory additionally to total petroleum hydrocarbons (C10-C40), since they have harmonised classification (i.e. diesel has HP 7 'Carcinogenic' with concentration limit of 0.1%). The precise CAS No should be attributed by the laboratory;
- The expression of the concentration of (total) PCB should be done according to EN 12766-1 and EN 12766-2 (EU 2018) (petroleum products and used oils): the total PCB content is calculated as five times the sum of the concentrations of the 6 congeners 28, 52, 101, 138, 153 and 180 (method B). These congeners represent in fact about 20% of the mass of all the congeners in the commercial mixtures (with variations according to the rate of chlorination thereof);
- Some POP substances (Table 4) requires specific laboratory methods;
- The extraction yield of additives in plastics (brominated flame retardants in fire-protected plastics, pesticides in packaging), must be checked with reference material. These analyses are best done in industrial (product control) laboratories rather than environmental laboratories.

For HP 1 'Explosive', HP 2 'Oxidising', HP 3 'Flammable', HP 12 'Release of an acute toxic gas' and HP 14 'Ecotoxic', laboratory tests complements the laboratory analyses, or are the preferred methods. These tests will be presented with these HPs.

6. HAZARD STATEMENT CODES

A third step is to gather the hazard statement codes (HSC) of substances found or assessed in the waste. The EU "harmonised" classification of Table 3.1 of Annex VI of the CLP Regulation (CLP 2008) and its different adaptations to technical progress (ATP) should first be used (spreadsheet file: https://echa.europa.eu/information-on-chemicals/annex-vi-to-clp). The ECHA's Classification and Labelling (C & L Inventory) database (with the information of Table 3.1 (blue-headed tables), and the classification by the notifiers (yellow-headed tables)) (http://echa.europa.eu/web/guest/information-on-chemicals/cl-inventory-database). These last

data are not validated by ECHA but can be used in the absence of harmonized classification. In France, the portal of chemicals of INERIS (http://www.ineris.fr/substances/fr/) is also taken as a reference (bilingual English/French).

7. SPECIATION

The laboratory delivers a **total elemental concentration for each element**, and a **substance concentration for organic substances**. The elements have no hazard statement codes (HSC), excepted for 11 with generic classification (see Table 1).

Table 1 : Generic classification of 11 elements (CLP 2008)

Element	Index No	Chemical international identification	Numboer of substances with a specific entry (« specified elsewhere »)	Hazard Class and Catergory	Hazard Statement Code
As	033-002-00-5	arsenic compounds, with the exception of those specified elsewhere in this Annex. Note 1	4	Acute Tox. 3 * Acute Tox. 3 * Aquatic Acute 1 Aquatic Chronic 1	H331 H301 H400 H410
	033-005-00-1	arsenic acid and its salts with the exception of those specified elsewhere in this Annex.	6	Carc. 1A Acute Tox. 3 * Acute Tox. 3 * Aquatic Acute 1 Aquatic Chronic 1	H350 H331 H301 H400 H410
Ba	056-002-00-7	barium salts, with the exception of barium sulphate, salts of 1-azo-2-hydroxynaphthalenyl aryl sulphonic acid, and of salts specified elsewhere in this Annex	9	Acute Tox. 4 * Acute Tox. 4 *	H332 H302
Be	004-002-00-2	beryllium compounds with the exception of aluminium beryllium silicates, and with those specified elsewhere in this Annex	2	Carc. 1B Acute Tox. 2 * Acute Tox. 3 * STOT RE 1 Eye Irrit. 2 STOT SE 3 Skin Irrit. 2 Skin Sens. 1 Aquatic Chronic 2	H350i H330 Cat2 H301 H372 ** H319 H335 H315 H317 H411
Cd	048-001-00-5	cadmium compounds, with the exception of cadmium sulphoselenide (xCdS.yCdSe), reaction mass of cadmium sulphide with zinc sulphide (xCdS.yZnS), reaction mass of cadmium sulphide with mercury sulphide (xCdS.yHgS), and those specified elsewhere in this Annex. Note 1	15	Acute Tox. 4 * Acute Tox. 4 * Acute Tox. 4 * Aquatic Acute 1 Aquatic Chronic 1	H332 H312 H302 H400 H410
Cr(VI)	024-017-00-8	chromium (VI) compounds, with the exception of barium chromate and of compounds specified elsewhere in this Annex	19	Carc. 1B Skin Sens. 1 Aquatic Acute 1 Aquatic Chronic 1	H350i H317 H400 H410
Hg	080-002-00-6	inorganic compounds of mercury with the exception of mercuric sulphide and those specified elsewhere in this Annex. Note 1	6	Acute Tox. 2 * Acute Tox. 1 Acute Tox. 2 * STOT RE 2 * Aquatic Acute 1 Aquatic Chronic 1	H330 Cat2 H310 H300 Cat2 H373 ** H400 H410
	080-004-00-7	organic compounds of mercury with the exception of those specifie. Note 1	7		
Pb	082-001-00-6	lead compounds with the exception of those specified elsewhere in this Annex. Note 1	17	Repr. 1A Acute Tox. 4 * Acute Tox. 4 * STOT RE 2 *	H360Df H332 H302 H373 **

Element	Index No	Chemical international identification	Numboer of substances with a specific entry (« specified elsewhere »)	Hazard Class and Catergory	Hazard Statement Code
				Aquatic Acute 1 Aquatic Chronic 1	H400 H410
Sb	051-003-00-9	antimony compounds, with the exception of the tetroxide (Sb2O4), pentoxide (Sb2O5), trisulphide (Sb2S3), pentasulphide (Sb2S5) and those specified elsewhere in this Annex. Note 1	7	Acute Tox. 4 * Acute Tox. 4 * Aquatic Chronic 2	H332 H302 H411
Se	034-002-00-8	selenium compounds with the exception of cadmium sulphoselenide and those specified elsewhere in this Annex	5	Acute Tox. 3 * Acute Tox. 3 * STOT RE 2 Aquatic Acute 1 Aquatic Chronic 1	H331 H301 H373** H400 H410
Tl	081-002-00-9	thallium compounds, with the exception of those specified elsewhere in this Annex	3	Acute Tox. 2 * Acute Tox. 2 * STOT RE 2 * Aquatic Chronic 2	H330 Cat2 H300 Cat2 H373 ** H411
U	092-002-00-3	uranium compounds with the exception of those specified elsewhere in this Annex	2	Acute Tox. 2 * Acute Tox. 2 * STOT RE 2 Aquatic Chronic 2	H330 Cat2 H300 Cat2 H373** H411

So, the fourth step is speciation of elemental concentrations into mineral substances concentrations. Some forms or substances have specific methods:
- Calcium oxide or hydroxide (important for HP 14 in thermal process residues (slag, bottom ash, ash) and limed waste (sludge from WWTP) or containing lime (concretes and mortars for demolition)) should be measured according to EN 1744-1 (aggregates, not suitable for low concentrations) or EN 451-1 (fly ash). The EN 459-2 (building lime) and the EN 196-2 (cement) should not be used for another waste/material. Quicklime CaO and hydrated lime $Ca(OH)_2$ can be differentiated by thermogravimetry (quantification of the loss of water during heating). These analyses are carried out by laboratories specialized in studies and research on building materials;
- Chromium (VI) also called chromate is measured by EN 15192.

Specialised laboratory methods are available for speciation: X-ray diffraction (limit of quantification 5% - 1%), thermogravimetry (0.5%), specific extraction and analysis (as calcium oxide and chromate), and extraction at different pH with geomodelling (10 mg/kg). These methods are not practiced in routine characterisation of waste, excepted Cr (VI). A synthesis can be found in AFNOR FD X30-494:2015.

A first simple approach is to calculate **"worst realistic case" substances concentrations** (Table 2), using among other information of the leaching concentrations. If the waste is calculated not hazardous, the assessment can be stopped.

7.1 Presentation of the list

The list is presented by element, because it often happens that one or two elements known in advance can according to their concentration classify or not the waste as hazardous, and this table thus allows a first approach more quickly. The elements are presented in the following order: major elements (of the earth's crust), major anions, 12 "heavy metals", and various minor, rare or little sought-after elements.

7.2 Choice of substances "worst realistic case"

1. Generic hazard statements are used primarily because they avoid hypotheses of speciation in substances. It is necessary to check in the Harmonized Table for the hazard statements for

substances (Annex VI of CLP) that the "other substances" of the same element (most often chemical industry intermediates, or highly reactive substances not found in common waste) are not in the waste. Substances with only one hazardous elements are preferred (i.e. lead sulfate rather than lead arsenate);

2. Soluble forms if they have the relevant hazard statement codes (sulphate - higher molar mass - for most properties, and chloride in some cases) are then used because they are often biologically more active, and their presence and concentration may be verified by leachable concentrations (EN 12457-2);

3. The most hydrated forms are chosen because the concentration of element is lower for a given substance concentration;

4. In the absence of soluble forms, simple oxides (and among families of oxides, the most present form in the natural environment) have been chosen;

5. Of the major elements, only those forming acids and strong bases with hazard statements were used. Elementary forms (metal, oxidation stage 0) and very reactive forms, especially with water (hydrides, ...) were not retained, with one exception: elemental lithium, present in some cells and batteries 2% rechargeable. The case of glass wool (index No. 650-016-00-2, H351), refractory ceramic fibres (index No. 650-017-00-8, H350), glass microfibers (fibre optic index No. ° 014-046-00-4 H350 and glass fibre index no. 014-047-00-X H351) (see file Annex VI of the CLP mentioned above) has not been considered here;

6. Finally, when only one substance in the element has the relevant hazard statement, it is chosen, even if it is rare. Example: The only lead substance with the hazard statement H350 for the property HP 7 'Carcinogenic' is a sulfo-chromic pigment, with a lead concentration limit of 0.1%.

The conversion of the substance concentration into the elemental concentration is obtained by multiplication by the mass percentage of the element in the substance (ratio of the atomic mass of the element multiplied by its stoichiometric coefficient, and the molar mass of the substance. substance).

7.3 Indications of presence of these forms "worst realistic case" in the waste

The presence and concentration of the chosen soluble forms (sulfate for most properties and chloride in some cases) can be verified by leachable concentrations (EN 12457-2). The pH and buffering capacity indicates whether acids (Cl, F, S, P, N) or bases (Na, Ca) are present and at which concentration (XP CEN/TS 15364). The redox potential and the redox capacity indicate whether [Cr (VI), Mn (VII)] or reducing [Fe (II)] oxidants are present and at which concentration (XP CEN/TS 16660). Xxx Calcium oxide and chromate have specific analytical methods (see Analysis section).

7.4 Using the table

For properties defined by concentration maxima (denoted Max HP 5, Max HP 7, Max HP 10, HP Max 11, Max HP 13), if the total concentration of the element in the waste is less than the concentration limit of the "worst realistic case", the waste is not hazardous for this property by this element.

For the properties defined by sums of concentration (denoted Σ HP 4, Σ HP 6, Σ HP 8, Σ HP 14), the concentrations of the substances of all the elements plus the concentrations of relevant organic substances must be added according to the hazard statements according to the rules of the Table 3. CLP "Note 1" means that the concentration limit applies to the element.

The HP 14 property is presented for the three hazard statements H400, H410 and H411, given that 50% of the hazardous waste is, in addition to the other properties, ecotoxic (according to our observations with the M-factors system). Without M-factors, the sum of acute ecotoxic substances H400 must reach 25% of the waste, and the waste will almost never be ecotoxic acute. The rule that classifies waste is that of chronic ecotoxicity. Virtually all acute ecotoxic substances H400 are also ecotoxic chronic H410. Manganese may have one form with H410 hazard statement code and another with H411 HSC, which justifies two different lines for chronic H14. Substances with hazard statements H412 and H413 are less numerous. Mineral substances ("worst-case realistic" approach) with the hazard statement H412 are $SnCl_4$ (CAS No. 7646-78-8) and powdered nickel <1 mm (CAS No. 7440-02-0). Mineral substances ("worst-case realistic" approach) with the hazard statement H413 are cadmium sulphide (CAS No. 1306-23-6), various nickel oxides (i.e. CAS No. 11099-02-8), and the elements Co, Se, Th and U (at the zero-oxidation stage). Waste with concentrations of 25% of these elements are resources.

Table 2: Concentration limits (LC) in substance and element by "worst realistic case" approach for 36 elements and 9 HP hazard properties by calculation

Element	Hazard Statement Code	CL by substance	« worst realistic case » substance	Formula	CAS No	CL by element	HP
Majors elements (cations)							
Si							.all
Al							.all
Fe	H315 H319	20%	Ferrous sulfate heptahydrate	FeSO4.7H2O	7782-63-0	4.0178%	∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Mn							∑ HP 4
	H373	10%	Manganese sulphate	MnSO4	7785-87-7	3.6383%	Max HP 5
	H302	25%	Potassium permanganate	KMnO4	7722-64-7	8.6911%	∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
	H400	25.00%	Potassium permanganate	KMnO4	7722-64-7	8.6911%	∑ HP 14 H400
	H410	0.25%	Potassium permanganate	KMnO4	7722-64-7	0.0869%	∑ HP 14 H410 H411
	H411	2.50%	If not KMnO4 (H400, H410) : MnSO4	MnSO4	7785-87-7	9.0957%	∑ HP 14 H410 H411
Ca	H319	20%	Calcium chloride	CaCl2	10043-52-4	7.2232%	∑ HP 4
	H315 H318	10%	Calcium oxide	CaO	1305-78-8	7.1470%	∑ HP 4
	H335	20%	Calcium oxide	CaO	1305-78-8	14.2939%	Max HP 5
							∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Mg							.all
Na	H314 1A	1%	Sodium hydroxide; caustic soda	NaOH	1310-73-2	0.5748%	∑ HP 4

Element	Hazard Statement Code	CL by substance	« worst realistic case » substance	Formula	CAS No	CL by element	HP
							Max HP 5
							∑ HP 6
							Max HP 7
	H314 1A	5%	Sodium hydroxide; caustic soda	NaOH	1310-73-2	2.8740%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
K	H315 H319	20%	Potassium chromate	K2CrO4	7789-00-6	8.0537%	∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314	5%	Potassium bifluoride; potassium hydrogen difluoride	F2HK	7789-29-9	2.5031%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Cr III							.all
V							∑ HP 4
	H372	1%	Divanadium pentaoxide; vanadium pentoxide	V2O5	1314-62-1	0.5602%	Max HP 5
	H302	25%	Divanadium pentaoxide; vanadium pentoxide	V2O5	1314-62-1	7.0021%	∑ HP 6
							Max HP 7
							∑ HP 8
	H361	3.00%	Divanadium pentaoxide; vanadium pentoxide	V2O5	1314-62-1	1.6805%	Max HP 10
	H341	1.00%	Divanadium pentaoxide; vanadium pentoxide	V2O5	1314-62-1	0.5602%	Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
	H411	2.50%	Divanadium pentaoxide; vanadium pentoxide	V2O5	1314-62-1	14.0041%	∑ HP 14 H410 H411
Major elements (anions)							
S	H314 1A	1%	Sulphuric acid ... % (concentration > 1%)	H2SO4	7664-93-9	0.2543%	∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314 1A	5%	Sulphuric acid ... % (concentration > 5%)	H2SO4	7664-93-9	1.2714%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
P							∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314 1B	5.00%	Phosphoric acid ... %, orthophosphoric acid ... %	H3PO4	7664-38-2	1.5804%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Cl							∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314 1B	5%	Hydrochloric acid ... % (concentration >5%)	HCl	7647-01-0	4.8619%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
F	H314 1A	1%	Hydrofluoric acid ... % (concentration > 1%)	HF	7664-39-3	0.9497%	∑ HP 4
							Max HP 5

Element	Hazard Statement Code	CL by substance	« worst realistic case » substance	Formula	CAS No	CL by element	HP
	H300 Cat 2	0.25%	Hydrofluoric acid ... % (concentration > 0.25%)	HF	7664-39-3	0.2374%	∑ HP 6
							Max HP 7
	H314 1A	5%	Hydrofluoric acid ... % (concentration >5%)	HF	7664-39-3	4.7483%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
N	H314 1A	1%	Nitric acid ... % (concentration > 1%)	HNO3	7697-37-2	0.2223%	∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314 1A	5%	Nitric acid ... % (concentration > 5%)	HNO3	7697-37-2	1.1114%	∑ HP 8
							Max HP 10
	N						Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
B	H318	10%	Perboric acid, sodium salt, tetrahydrate = sodium perborate tetrahydrate	NaBO3.4H2O	10486-00-7	0.7024%	∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
							∑ HP 8
	H360	0.30%	Disodium tetraborate decahydrate; borax decahydrate	Na2B4O7.10H2O	1303-96-4	0.0340%	Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
« Heavy metals »							
As							∑ HP 4
							Max HP 5
	H300 Cat 2	0.25%	Diarsenic trioxide; arsenic trioxide	As2O3	1327-53-3	0.1893%	∑ HP 6
	H350	0.10%	Arsenic acid and its salts with the exception of those specified elsewhere in this Annex	H3AsO4	7778-39-4	0.0528%	Max HP 7
	H314	5%	Diarsenic trioxide; arsenic trioxide	As2O3	1327-53-3	3.7870%	∑ HP 8
	H360	0.30%	Lead hydrogen arsenate	PbHAsO4	7784-40-9	0.0648%	Max HP 10
							Max HP 11
							Max HP 13
	H400	25.00%	Generic classification (substance not defined). Note 1	As		25.0000%	∑ HP 14 H400
	H410	0.25%	Generic classification (substance not defined). Note 1	As		0.2500%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Ba							∑ HP 4
							Max HP 5
	H301 H332	5.00%	Barium chloride	BaCl2	10361-37-2	3.2975%	∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Cd							∑ HP 4
	H372	1%	Cadmium sulfate	CdSO4	10124-36-4	0.5392%	Max HP 5
	H301 H330 Cat 2	0.50%	Cadmium sulfate	CdSO4	10124-36-4	0.2696%	∑ HP 6
	H350	0.10%	Cadmium sulfate	CdSO4	10124-36-4	0.0539%	Max HP 7
							∑ HP 8
	H360	0.30%	Cadmium sulfate	CdSO4	10124-36-4	0.1618%	Max HP 10
	H340	0.10%	Cadmium sulfate	CdSO4	10124-36-4	0.0539%	Max HP 11
							Max HP 13
	H400	25.00%	Generic classification (substance not defined). Note 1	Cd	10124-36-4	25.0000%	∑ HP 14 H400
	H410	0.25%	Generic classification (substance not defined). Note 1	Cd	10124-36-4	0.2500%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Cr VI							∑ HP 4
	H372	1%	Sodium chromate	Na2CrO4	7775-11-3	0.3210%	Max HP 5

Element	Hazard Statement Code	CL by substance	« worst realistic case » substance	Formula	CAS No	CL by element	HP
	H301 H312 H330 Cat 2	0.50%	Sodium chromate	Na2CrO4	7775-11-3	0.1606%	∑ HP 6
	H350	0.10%	Sodium chromate or Generic classification	Na2CrO4	03/11/7775	0.0321%	Max HP 7
	H314	5%	Sodium chromate	Na2CrO4	7775-11-3	1.6051%	∑ HP 8
	H360	0.30%	Sodium chromate	Na2CrO4	7775-11-3	0.0963%	Max HP 10
	H340	0.10%	Sodium chromate	Na2CrO4	7775-11-3	0.0321%	Max HP 11
	H317 H334	10%	Sodium chromate	Na2CrO4	7775-11-3	3.2102%	Max HP 13
	H400	25.00%	Sodium chromate or Generic classification	Na2CrO4	7775-11-3	8.0250%	∑ HP 14 H400
	H410	0.25%	Sodium chromate or Generic classification	Na2CrO4	7775-11-3	0.0803%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Cu	H315 H319	20%	Copper sulfate	CuSO4.5H20	7758-98-7	5.0905%	∑ HP 4
							Max HP 5
	H302	25%	Copper sulfate	CuSO4.5H20	7758-98-7	6.3631%	∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
	H400	25.00%	Copper sulfate	CuSO4.5H20	7758-98-7	6.3631%	∑ HP 14 H400
	H410	0.25%	Copper sulfate	CuSO4.5H20	7758-98-7	0.0636%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Hg	H315 H319	20%	Mercury (I) chloride	Hg2Cl2	10112-91-1	17.2440%	∑ HP 4
	H372	1%	Mercuric chloride	HgCl2	7487-94-7	0.7578%	Max HP 5
	H300 Cat 2	0.25%	Generic classification (substance not defined). Note 1	Hg	7783-35-9	0.2500%	∑ HP 6
							Max HP 7
	H314	5%	Mercuric chloride	HgCl2	7487-94-7	3.7889%	∑ HP 8
	H360	0.30%	Mercury	Hg	7439-97-6	0.3000%	Max HP 10
	H341	1.00%	Mercuric chloride	HgCl2	7487-94-7	0.7578%	Max HP 11
							Max HP 13
	H400	25.00%	Generic classification (substance not defined). Note 1	Hg	7783-35-9	25.0000%	∑ HP 14 H400
	H410	0.25%	Generic classification (substance not defined). Note 1	Hg	7783-35-9	0.2500%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Mo							∑ HP 4
							Max HP 5
							∑ HP 6
	H351	1.00%	Molybdenum trioxide	MoO3	1313-27-5	0.6665%	Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Ni	H318	10%	Nickel dinitrate	Ni(NO3)2	13138-45-9	3.2126%	∑ HP 4
	H372	1%	Nickelous sulfate	NiSO4	7786-81-4	0.3793%	Max HP 5
	H331	3.50%	Nickel dichloride	NiCl2	7718-54-9	1.5853%	∑ HP 6
	H350	0.10%	Nickelous sulfate	NiSO4	7786-81-4	0.0379%	Max HP 7
							∑ HP 8
	H360	0.30%	Nickelous sulfate	NiSO4	7786-81-4	0.1138%	Max HP 10
	H341	1.00%	Nickelous sulfate	NiSO4	7786-81-4	0.3793%	Max HP 11
	H317 H334	10%	Nickelous sulfate	NiSO4	7786-81-4	3.7934%	Max HP 13
	H400	25.00%	Nickelous sulfate	NiSO4	7786-81-4	9.4807%	∑ HP 14 H400
	H410	0.25%	Nickelous sulfate	NiSO4	7786-81-4	0.0948%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Pb							∑ HP 4
	H373	10%	Generic classification (substance not defined). Note 1	Pb		10.00%	Max HP 5
	H332	22.50%	Generic classification (substance not defined). Note 1	Pb		22.50%	∑ HP 6
	H350	0.10%	Only: Lead sulfochromate yellow; C.I. Pigment Yellow 34; [This substance is identified in the Colour Index by Colour Index Constitution Number, C.I. 77603.]. Note 1	Pb	1344-37-2	0.10%	Max HP 7
							∑ HP 8
	H360	0.30%	Generic classification (substance not defined). Note 1	Pb		0.30%	Max HP 10
							Max HP 11
							Max HP 13
	H400	25.00%	Generic classification (substance not defined). Note 1	Pb		25.00%	∑ HP 14 H400
	H410	0.25%	Generic classification (substance not defined). Note 1	Pb		0.25%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Sb							∑ HP 4

Element	Hazard Statement Code	CL by substance	« worst realistic case » substance	Formula	CAS No	CL by element	HP
							Max HP 5
	H301	5.00%	Antimony trifluoride	SbF3	7783-56-4	3.4058%	∑ HP 6
	H351	1.00%	Antimony trioxide	Sb2O3	1309-64-4	0.8353%	Max HP 7
	H314	5%	Antimony pentachloride	SbCl5	7647-18-9	2.0358%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
	H411	2.50%	Generic classification (substance not defined). Note 1	Sb	-	25.0000%	∑ HP 14 H410 H411
							∑ HP 4
	H373	10%	Generic classification (substance not defined) / Hyp. selenium dioxide	SeO2	7446-08-4	7.1165%	Max HP 5
	H300 Cat 2	0.25%	Sodium selenite	Na2SeO3	10102-18-8	0.1142%	∑ HP 6
							Max HP 7
							∑ HP 8
Se							Max HP 10
							Max HP 11
	H317	10%	Sodium selenite	Na2SeO3	10102-18-8	4.5662%	Max HP 13
	H400	25.00%	Generic classification (substance not defined) / Hyp. selenium dioxide	SeO2	7446-08-4	17.7912%	SeO2
	H410	0.25%	Generic classification (substance not defined) / Hyp. selenium dioxide	SeO2	7446-08-4	0.1779%	∑ HP 14 H410 H411
	H411	2.50%	Sodium selenite	Na2SeO3	10102-18-8	1.1416%	∑ HP 14 H410 H411
	H318	10%	Zinc sulphate (hydrous) (mono-, hexa- and hepta hydrate)	ZnSO4:7H2O	7446-19-7	2.2747%	∑ HP 4
							Max HP 5
	H302	25%	Zinc sulphate (hydrous) (mono-, hexa- and hepta hydrate)	ZnSO4:7H2O	7446-19-7	5.6866%	∑ HP 6
							Max HP 7
Zn	H314	5%	Zinc chloride	ZnCl2	7646-85-7	2.3986%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
	H400	25.00%	Zinc chloride	ZnCl2		11.9950%	∑ HP 14 H400
	H410	0.25%	Zinc chloride	ZnCl2		0.1199%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Minor and rare elements							
							∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314	5%	Silver nitrate	AgNO3	7761-88-8	3.1750%	∑ HP 8
Ag							Max HP 10
							Max HP 11
							Max HP 13
	H400	25.00%	Silver nitrate	AgNO3	7761-88-8	15.8751%	∑ HP 14 H400
	H410	0.25%	Silver nitrate	AgNO3	7761-88-8	0.1587%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411
	H315 H319	10%	Generic classification (substance not defined) / Hyp. beryllium hydroxide	Be(OH)2	13327-32-7	2.0946%	∑ HP 4
	H372	1%	Generic classification (substance not defined) / Hyp. beryllium hydroxide	Be(OH)2	13327-32-7	0.2095%	Max HP 5
	H301	5.00%	Generic classification (substance not defined) / Hyp. beryllium hydroxide	Be(OH)2	13327-32-7	1.0473%	∑ HP 6
	H350	0.10%	Generic classification (substance not defined) / Hyp. beryllium hydroxide	Be(OH)2	13327-32-7	0.0209%	Max HP 7
Be							∑ HP 8
							Max HP 10
							Max HP 11
	H317	10%	Generic classification (substance not defined) / Hyp. beryllium hydroxide	Be(OH)2	13327-32-7	2.0946%	Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
	H411	2.50%	Generic classification (substance not defined) / Hyp. beryllium hydroxide	Be(OH)2	13327-32-7	0.5237%	∑ HP 14 H410 H411
							∑ HP 4
							Max HP 5
	H302	25.00%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	25.0000%	∑ HP 6
	H350	0.10%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	0.1000%	Max HP 7
							∑ HP 8
Co	H360	0.30%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	0.3000%	Max HP 10
	H341	1.00%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	1.0000%	Max HP 11
	H317 H334	10%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	10.0000%	Max HP 13
	H400	25.00%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	25.0000%	∑ HP 14 H400
	H410	0.25%	Cobalt sulfate. Note 1	CoSO4	10124-43-3	0.2500%	∑ HP 14 H410 H411
							∑ HP 14 H410 H411

Element	Hazard Statement Code	CL by substance	« worst realistic case » substance	Formula	CAS No	CL by element	HP
Li							∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314	5%	Lithium (element)	Li	7439-93-2	5.0000%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Sn							∑ HP 4
							Max HP 5
							∑ HP 6
							Max HP 7
	H314	5%	Tin tetrachloride; stannic chloride	SnCl4	7646-78-8	2.2781%	∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
							∑ HP 14 H410 H411
Tl	H315	20%	Dithallium sulphate; thallic sulphate	Tl2SO4	7446-18-6	16.1944%	∑ HP 4
	H372	1%	Dithallium sulphate; thallic sulphate	Tl2SO4	7446-18-6	0.8097%	Max HP 5
	H373	10%	Generic classification (substance not defined) / Hyp. thallium(III) oxide	Tl2O3	7446-18-6	8.9492%	Max HP 5
	H300 Cat2	0.25%	Dithallium sulphate; thallic sulphate	Tl2SO4	7446-18-6	0.2024%	∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
	H411	2.50%	Generic classification (substance not defined) / Hyp. thallium(III) oxide	Tl2O3	-	2.2373%	∑ HP 14 H410 H411
U							∑ HP 4
	H373	10%	Generic classification (substance not defined) / Hyp. uranium oxide	UO2		8.8120%	Max HP 5
	H300 Cat2	0.25%	Generic classification (substance not defined) / Hyp. uranium oxide	UO2		0.2203%	∑ HP 6
							Max HP 7
							∑ HP 8
							Max HP 10
							Max HP 11
							Max HP 13
							∑ HP 14 H400
							∑ HP 14 H410 H411
	H411	2.50%	Generic classification (substance not defined) / Hyp. uranium oxide	UO2	-	22.0375%	∑ HP 14 H410 H411

8. HAZARD PROPERTIES

In the fifth step, the hazard properties can be assessed by applying classification rules (Table 3). Concentrations of substances lower than the cut-off values must not be considered. Waste can also be hazardous by some POP substances (Table 4).

Table 3 : Hazard properties by calculation (EU 2014b)

HP	Hazard	Hazard Class and Category codes Hazard Statement Codes	Cut-off values	Concentration limits
HP 4	Irritant (Skin irritation and eye damage)	H314 Skin corr. 1A H318 Eye dam. 1 H315 Skin irrit. 2, H319 Eye irrit. 2	1 %	**A :** ∑ H314 1A ≥ 1 % **B :** ∑ H318 ≥ 10 % **C :** ∑ (H315 et H319) ≥ 20 %

HP	Hazard	Hazard Class and Category codes Hazard Statement Codes	Cut-off values	Concentration limits
HP 5	Specific target organ toxicity/Aspiration Toxicity	H370 STOT SE 1 H371 STOT SE 2 H335 STOT SE 3 H372 STOT RE 1 H373 STOT RE 2 H304 Asp. Tox. 1	/	**A :** max (H370) ≥ 1 % **B :** max (H371) ≥ 10 % **C :** max (H335) ≥ 20 % **D :** max (H372) ≥ 1 % **E :** max (H373) ≥ 10 % **F :** max (H304) ≥ 10 % **G :** ∑ H304 ≥ 10 % et viscosité cinématique globale du déchet à 40 °C < 20,5 mm²/s
HP 6	Acute Toxicity	H300 Acute Tox.1 (Oral) H300 Acute Tox. 2 (Oral H301 Acute Tox. 3 (Oral) H302 Acute Tox 4 (Oral) H310 Acute Tox.1 (Dermal) H310 Acute Tox.2 (Dermal) H311 Acute Tox. 3 (Dermal) H312 Acute Tox 4 (Dermal) H330 Acute Tox 1 (Inhal.) H330 Acute Tox.2 (Inhal.) H331 Acute Tox. 3 (Inhal.) H332 Acute Tox. 4 (Inhal.)	Cat. 1, 2 ou 3 : 0,1 % Cat. 4 : 1 %	**A :** ∑ H300 cat. 1 ≥ 0,1 % **B :** ∑ H300 cat. 2 ≥ 0,25 % **C :** ∑ H301 ≥ 5 % **D :** ∑ H302 ≥ 25 % **E :** ∑ H310 cat. 1 ≥ 0,25 % **F :** ∑ H310 cat. 2 ≥ 2,5 % **G :** ∑ H311 ≥ 15 % **H :** ∑ H312 ≥ 55 % **I :** ∑ H330 cat. 1 ≥ 0,1 % **J :** ∑ H330 cat. 2 ≥ 0,5 % **K :** ∑ H331 ≥ 3,5 % **L :** ∑ H332 ≥ 22,5 %
HP 7	Carcinogenic	H350 Carc. 1A et 1B H351 Carc. 2	/	**A :** max (H350) ≥ 0,1 % **B :** max (H351) ≥ 1 %
HP 8	Corrosive	H314 Skin Corr. 1A, 1B et 1C	1 %	**A :** ∑ H314 ≥ 5 %
HP 10	Toxic for reproduction	H360 Repr. 1A et 1B H361 Repr. 2	/	**A :** max (H360) ≥ 0,3 % **B :** max (H361) ≥ 3 %
HP 11	Mutagenic	H340 Muta. 1A et 1B H341 Muta. 2	/	**A :** max (H340) ≥ 0,1 % **B :** max (H341) ≥ 1 %
HP 13	Sensitising	H317, H334	/	**A :** max (H317) ≥ 10 % **B :** max(H334) ≥ 10 %
HP 14	Ecotoxic	H400 Aquatic Acute 1 H410 Aquatic Chronic 1 H411 Aquatic Chronic 2 H412 Aquatic Chronic 3 H413 Aquatic Chronic 4 H420	Cat. 1 : 0,1 % Cat. 2, 3 ou 4 : 1 %	**A** : ∑ H400 ≥ 25 % **B** : ∑ (100 * H410) + (10 * H411) + (H412) ≥ 25% **C** : ∑ (H410 + H411 + H412 + H413) ≥ 25 % **D** : max (H420) ≥ 0,1 %

Table 4 : Hazard property by POP substances (EC 2008 and updates)

Substance	CAS No	EC No	Waste hazardous if concentration > CL (2014/ 955/UE)	Concentration limit of the POP regulation
Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF)			X	15 µg/kg (= 0.0000015 %) (Toxicity Equivalent Factors for congeners in the POP regulation)
DDT (1,1,1-trichloro-2-2-bis(4-chlorophenyl)ethane)	50-29-3	200-024-3	X	50 mg/kg (= 0.005 %)
Chlordane	57-74-9	200-349-0	X	50 mg/kg (= 0.005 %)
Hexachlorocyclohexanes, including lindane	58-89-9 319-84-6 319-85-7 608-73-1	210-168-9 200-401-2 206-270-8 206-271-3	X	50 mg/kg (= 0.005 %)
Dieldrine	60-57-1	200-484-5	X	50 mg/kg (= 0.005 %)
Endrine	72-20-8	200-775-7	X	50 mg/kg (= 0.005 %)
Heptachlore	76-44-8	200-962-3	X	50 mg/kg (= 0.005 %)
Hexachlorobenzene	118-74-1	200-273-9	X	50 mg/kg (= 0.005 %)
Chlordecone	143-50-0	205-601-3	X	50 mg/kg (= 0.005 %)
Aldrine	309-00-2	206-215-8	X	50 mg/kg (= 0.005 %)
Pentachlorobenzene	608-93-5	210-172-5	X	50 mg/kg (= 0.005 %)
Polychlorobiphenyles (PCB)	1336-36-3 and others	215-648-1	X	50 mg/kg (= 0.005 %)
Mirex	2385-85-5	219-196-6	X	50 mg/kg (= 0.005 %)
Toxaphene	8001-35-2	232-283-3	X	50 mg/kg (= 0.005 %)
Hexabromobiphenyle	36355-01-8	252-994-2	X	50 mg/kg (= 0.005 %)
Endosulfan	115-29-7 959-98-8 33213-65-9	204-079-4		50 mg/kg (= 0.005 %)
Hexachlorobutadiene	87-68-3	201-765-5		100 mg/kg (= 0.01 %)
Naphtalenes polychlores				10 mg/kg (= 0.001 %)
Alkanes C10-C13, chloro (short-chain chlorinated paraffins) (SCCPs)	85535-84-8	287-476-5	Lower CL by HP 14 H410: 0.25%	10 000 mg/kg (= 1 %)
Tetrabromodiphenylether $C_{12}H_6Br_4O$				Σ tetra-. penta-. hexa- et hepta-BDE : 1 000 mg/kg (= 0.1 %)
Pentabromodiphenylether $C_{12}H_5Br_5O$				
Hexabromodiphenylether $C_{12}H_4Br_6O$				
Heptabromodiphenylether $C_{12}H_3Br_7O$				
Decabromodiphenylether - Bis(pentabromophenyl) ether	1163-19-5	214-604-9		1 000 mg/kg for products (EU 2017b)

Substance	CAS No	EC No	Waste hazardous if concentration > CL (2014/ 955/UE)	Concentration limit of the POP regulation
Perfluorooctane sulfonic acid and its derivatives (PFOS) $C_8F_{17}SO_2X$ (X = OH, Metal salt (O-M +), halide, amide, and other derivatives including polymers)	1763-23-1 [1] 2795-39-3 [2] 70225-14-8 [3] 29081-56-9 [4] 29457-72-5 [5]	217-179-8 [1] 220-527-1 [2] 274-460-8 [3] 249-415-0 [4] 249-644-6 [5]		50 mg/kg (= 0.005 %)
Hexabromocyclododecane (HBCDD) 'Hexabromocyclododecane' means: HBCDD, 1,2,5,6,9,10-HBCDD and its main diastereoisomers: alpha- HBCDD; beta-HBCDD; and gamma- HBCDD	25637-99-4 3194-55-6 134237-50-6 134237-51-7 134237-52-8	247-148-4 221-695-9		1 000 mg/kg (= 0.1%). subject to review by the Commission by 20.4.2019
Candidate POP: Dicofol	115-32-2	204-082-0		
Candidate POP: Pentadecafluorooctanoic acid (perfluorooctanoic) (PFOA), its salts and derivatives	335-67-1	206-397-9		
Candidate POP: Perfluorohexane sulfonic acid (PFHxS), its salts and derivatives	355-46-4	206-587-1		

Most POP substances have also hazard statement codes (not shown in Table 4), and hence concentration limits for HPs. Only short chain chlorinated paraffins (SCCPs) have CL by HP lower than CL by POP regulation (column 4 of the Table).

8.1 Physical hazard

8.1.1 By tests: HP 1 'explosive', HP 2 'Oxidising', HP 3 'Flammable',

These HPs are defined by the presence of substances with relevant HSC. They are in practice assessed by expert judgment and origin of the waste, or by tests (Table 5). It has been recently proposed to calculate them if the chemical composition is known in detail (EU 2018). The internet site HazWasteOnline (see below) assess HP 3 with total petroleum hydrocarbon analysis. The most used methods are EC A9 (flash point for liquid waste) and UN N1 (speed of flame progression in a row of solid waste).

Table 5 : Tests for HP 1, HP 2, HP 3

HP properties	Definition of "product"	Methods
HP1 Explosive	Substances and preparations which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene	EC Method A14: thermal and mechanical sensitivities (impact and friction)
HP2 Oxidizing	Substances and preparations which, in contact with other substances, particularly flammable substances, present a highly exothermic reaction	Gas: Method ISO 10156 (paragraph 5) Liquids: UN O2 test (liquid oxidizers) Solids: UN test O1 (oxidizing solids)
HP3-A Highly flammable	Substances and preparations: in liquid form, with a flash point below 21 ° C, or	EC method A9
	which may become hot and finally catch fire in air at ambient temperature without any input of energy, or	Test UN N2 (pyrophoric solids) or UN N3 (pyrophoric liquids) and UN N4 (solid, self-heating)
	In the solid state, which may readily catch fire after brief contact with a source of ignition and which continue to burn or to be consumed after removal of the source of ignition, or	Test UN N1 (flammable solids)
	in the gaseous state, which are flammable in air at normal pressure, or	A11 EC method or a method of ISO 10156 (paragraph 4) standard
	which, in contact with water or damp air, evolve highly flammable gases in hazardous quantities.	Test UN N5 (substances which, in contact with water, emit flammable gases)
HP3-B Flammable	Liquid substances and preparations having a flash point equal to or greater than 21 ° C and less than or equal to 55 ° C	EC method A9

8.2 (Human) Toxicity

8.2.1 By analysis and calculation: HP 4 'Irritant — skin irritation and eye damage', HP 6 'Acute Toxicity", HP 8 'Corrosive' (sums of concentrations); HP 5 'Specific target organ toxicity (STOT)/Aspiration Toxicity', HP 7 'Carcinogenic', HP 10 'Toxic for reproduction, HP 11

'Mutagenic', HP 13 'Sensitising', HP 'POP' (maxima of concentrations)

These HPs are typically calculated from chemical composition (Table 3). Biological tests have been evoked (EU 2018), without further precision.
By list: HP 9 'Infectious'

It is proposed to use the UN ADR list of infectious organisms, or the origin of the waste, or an expert judgment (ADR 2014). A technical report is available (Hennebert 2017a).

8.2.2 By test: HP 12 'Release of an acute toxic gas'

The definition of HP 12 is that waste contains substances with HSC EUH029, EUH031 and EUH032. These (very) reactive substances are not analysed in routine environmental laboratories. Therefrom, it is proposed (Hennebert et al. 2016a):
1. Measurement of the volume of gases emitted into contact with water or an acid (manual or automated calcimeter in 5 min, solid/liquid ratio of 10 l/kg, acid 2.5 M HNO_3). The limit of quantification has been found at INERIS to be 0.1 litre of gas per kg of raw waste in 5 minutes;
2. If gas is emitted beyond that limit, check if one of the following gases is emitted: HCN, HF, PH3, H2S, SO2, HCl and Cl2 with for detection probes or simple qualitative colorimetric methods;
3. If one of these gases is detected, speciate the emitting substance (either by direct method if they are in high concentration or by calculation by the "worst case" method if they are in low concentrations, or by specific methods) and check whether they have a hazard statement code EUH029, EUH031 or EUH032, or alternatively check if the waste is likely to contain substances with these HSC (list in the publication).

8.3 Ecotoxicity

8.3.1 By analysis and calculation: HP 14 'Ecotoxic'

The calculation formulas are presented in Table 3.

Discussion on calculation methods
The method does not include the multiplier of concentration of the CLP (M-factors), developed by classificators of products to fine tune the calculated toxicity of less and more ecotoxic substances. The method with M-factors (CLP method limited to the level 1 and 2 of chronic ecotoxicity) has the best correspondence (80%) with the European List of Waste (Hennebert et al. 2014, 2016b, MEEM 2015). The list of harmonised M-factors is continuously completed (for instance 10 M-factors for copper in ATP9 of CLP (EU 2016). Some classification of waste with the two methods are presented in Table 6.

Table 6 : Waste less severely and more severely classified without multiplying factors for HP 14 'Ecotoxic' chronic by calculation

Chronic ecotoxicity	Concentration limits		Hazard HP 14 vs CLP	Example of elements (« realistic worst case ») or substance
M-factor	HP 14 : hazardous if $\sum [(100 * H410) + (10 * H411) + (H412)] \geq 25\%$	CLP chronic 2 : hazardous if		

		∑ [(10 * M * H410) + (H411)] ≥ 25%		
1 or no M	0.25% = 2 500 mg/kg	2.5% = 25 000 mg/kg	Overestimated by factor 10	Waste with Ag, Mn, Ni Plastics with brominated flame retardants
10	0.25% = 2 500 mg/kg	0.25% = 2 500 mg/kg	Equal	Waste with As, Co, Cr(VI), Cu, Pb, Se, Zn Waste with some PAH: anthracene, benzo(k)fluoranthene, fluoranthene, pyrene
100	0.25% = 2 500 mg/kg	0.025% = 250 mg/kg	Underestimated by factor 10	Waste with Cd, Hg Waste with PAH benzo(g,h,i)perylene Packaging and plastics with pesticide
1000 - 1000000	0.25% = 2 500 mg/kg	0.0025% = 25 mg/kg	Underestimated by factor 100…100000	Packaging and plastic with pesticide (i.e. chlorpyrifos M = 1 000 000)

Attributing an ecotoxicity hazard statement code H400 and H410 to H413 to an element

To avoid speciation hypothesis and to attribute a HSC to an element in a waste (whatever is/are the substance(s) of the element), a simple method is to compare the leachable fraction of this element to the lowest published EC50 of that element, and to attribute a HSC according to CLP rules. The ECHA Guidance document states that: "IV.2.3 Comparison of aquatic toxicity data and solubility data - A decision on whether or not the substance is classified will be made by comparing aquatic toxicity data and solubility data." (page 586 of ECHA 2017). The HSC is then attributed to the total concentration of the element (and not to the leachable concentration!). This approach has been proven to be consistent for a large set of waste with the European List of Waste classification and the calculation method with M-factors (Hennebert et al. 2016b). Tables of lowest EC50 are supplied in this later paper.

Bioavailability

The assessment of waste should consider the bioavailability of the substances (EU 2017, 2018). According to ECHA guideline: "In general, there are no specific environmental test methods developed to measure biological availability of substances or mixtures." (ECHA 2017). Bioavailability of elements and substances of waste is not measurable. The bioavailable fraction is not limited to the leachable fraction: ingestion, inhalation, dermal contact are significant routes of exposure. It seems today that the best method to assess bioavailability is to use a battery of biotests (Table 7).

Classification by calculation with leachable concentrations instead of total concentrations

The principle is to calculate the sum of substances using leachable concentrations, rather than total concentrations. Leachable concentrations of metals are typically 1/100 to 1/1000 of the total concentrations. This method classified 0 samples hazardous from 19 different waste, while the method with M-factors classified 12 samples hazardous (Hennebert et al. 2014). A similar result has been found by ECN for incinerator bottom ashes (CEWEP 2017): the 95th percentile of a set of bottom ashes was found not ecotoxic based on the leaching concentration, and ecotoxic based on the total content. Furthermore, the leaching concentrations were lower than the cut-off values (CEWEP 2017).

8.3.2 By tests: HP 14 'Ecotoxic'

It is recognised that test results prevail on calculation results (EU 2017a, EU 2018), due to not-enough-detailed chemical analysis, unknown antagonist or synergic effects, unknown bioavailability, and so on. An additional reason is that the actual calculation formula for waste do

not use the M-factors. No harmonised test battery is available at EU level. Building on a very large interlaboratory trial in 2006, French and German experts have proposed a test battery (Pandard and Römbke 2013), now without options and with validated concentration limits (Hennebert 2018) (Table 7). The proposed concentrations limits are simply the highest ecotoxic effect observed in a set of 10 waste non-hazardous by the European list of waste (taken as the reference) and well-studied from Belgium, France and Germany. They can be improved as more data of H or non-H by list (in particular from the Member States of the EU) are available. They have correctly classified 13 hazardous waste by list as ecotoxic.

Table 7 : Proposed Biotest battery for HP 14 with validated concentration limits (CL)

Test	Standard	Expression of results of the test: Concentration of waste generating 50% effect (EC_{50})	Duration	CL (in fraction of waste in the respective dilution medium): The waste is hazardous if measured EC_{50} < CL
Sample preparation	EN 15002, EN 14735 without pH adjustment			
Aquatic tests (liquid waste or leachate of solid waste)				
Inhibition of the light emission of *Vibrio fischeri* (Luminescent bacteria test)	EN ISO 11348-3 (2007)	Eluate concentration which results in 50% inhibition of light emission (EC_{50})	30 mn	EC_{50} < 15.8% rounded 15%
Freshwater algal growth inhibition test with *Pseudokirchneriella subcapitata*	EN ISO 8692 (2012)	Eluate concentration which results in 50% inhibition of population growth (EC_{50})	72 h	EC_{50} < 7.03% rounded 10%
Inhibition of the mobility of *Daphnia magna*	EN ISO 6341 (2012)	Eluate concentration which results in 50% inhibition of mobility (EC_{50})	48 h	EC_{50} < 7.95% rounded 10%
Terrestrial tests (solid waste)				
Soil contact test with *Arthrobacter globiformis*	ISO 18187 (2014)	Waste concentration which results in 50% inhibition of enzyme activity (EC_{50})	6 h	EC_{50} < 2.25% rounded 5%
Effects of chemicals on the emergence and growth of higher plants (*Brassica rapa*)	EN ISO 11269-2 (2012)	Waste concentration which results in 50% inhibition of growth (EC_{50})	14 d	EC_{50} < 13.7% rounded 15%
Avoidance test with earthworms (*Eisenia fetida*)	ISO 17512-1 (2007)	Waste concentration which affects behavior by 50% (EC_{50})	48 h	EC_{50} < 3.75% rounded 5%

<u>Discussion on neutralisation of leachate of alkaline waste before dilution and testing, or for some dilutions</u>

EN 14735:2006 “Characterization of waste - Preparation of waste samples for ecotoxicity tests” states at section 10.5 pH: “Tests shall be carried out without pH adjustment of the test portion. pH of all test mixtures is measured at the beginning and at the end of the test and reported.” And in a note (non-normative): “If toxic effects are observed in the dilutions where pH is not compatible with the survival of the organisms, the test(s) can be repeated with pH adjustment of the test portion.” As most elements (in particular in equilibrium with a solid phase) are more soluble in acid and alkaline pH domains (for instance CEWEP 2017), the pH adjustment (for some dilutions of the test portion or for the whole test portion) obviously will precipitate a significant part of the elements and reduce ecotoxicity beyond the effect of $[H^+]$ or $[OH^-]$ concentrations. The classification of the waste for the hazard property HP 14 ‘Ecotoxic’ can be modified. Experimental data have shown that neutralisation of the leachate before dilution deletes ecotoxicity, even when the final pH of the different mixtures of culture medium and waste leachate is the same. The effects are less if only the dilutions are neutralised. Neutralisation of leachates removes ecotoxicity, beyond the ecotoxicity of H^+ and OH^-. It should not be practiced.

To reduce ecotoxicity for beneficial use, prior to reuse or storage in contact with natural

environment, the waste flow should be preferably pre-treated or left freely evolving by natural carbonation and eventually leaching, to reach the desired pH and the corresponding lower soluble fraction of the element, like the “maturation” of the MSWI bottom ashes. If the soluble alkalinity in the waste is sodic or potassic, the waste can be pre-treated with soluble calcium (by addition of gypsum) and atmospheric CO_2. The soluble alkalinity will precipitate as calcium carbonate, and the pH of the liquid phase will be about 8.5 when the reaction is completed.

8.4 Capable of exhibiting a hazardous property not displayed by the original waste

Aside the presence of some very specific heating or explosive substances in confined environments with specific HSC (EU 2018), this HP needs a specific study. To consider: waste with reduced substances that can oxidise with negative environmental effects (sulphidic ores unbalanced by alkalinity, producing sulfuric acid and dissolved mined elements, acid mine drainage), substances that can be liberated by anaerobic biodegradation of organic matter (decay of marine algae producing toxic H2S) or on the long term by weathering of minerals, should be considered. The first case can be assessed by EN 15875.

9. INTERNET SITES

Fine-tuned classification of waste is not a routine job. Interactive sites like HazWasteOnline (https://www.hazwasteonline.com/ of OneTouch Data, UK) or ClassifyMyWaste (https://www.ecn.nl/classifymywaste/ of Energy Centre of the Netherlands, NL) are helpful in the speciation options, and provide reliable and up-to-date HSC, classification rules and classification reports. The first site, HazWasteOnline, has friendly interfaces for uploading the data of composition. The speciation options are proposed to the user. The site documents all the choices in a very complete report. The ClassifyMyWaste site offers worst case calculations for all the elements mentioned in the CLP. This first approach is very useful to identify elements of concern.

10. CONCLUSION

A complete set of methods is now available for proper classification of waste, becoming more important as more and more loops of material are created in the circular economy. Experience has shown that unexpected substances can be detected by the methods proposed here, allowing a better management of the matters and materials.

REFERENCES

ADR 2014. United Nations - The European Agreement on the International Transport of Dangerous Goods. The European Agreement on the International Transport of Dangerous Goods, Volume I. 1254 p. http://www.unece.org/fileadmin/DAM/trans/danger/publi/adr/adr2015/ADR2015e_WEB.pdf

AFNOR FD X30-494:2015. Abdelghafour M, David F, Domas J, Gemise-Fareau C, Hennebert P, Humez N, Laborde E, Louchez G, Piantone P, Rebischung F, Vernus E. 2015. Caracterization of waste – Speciation of elements in waste (in French). 19 p.

AFNOR X30-489:2013. Characterization of waste – Determination of the content of elements and substances in waste. AFNOR, France.

CEN/TR 15310-1 to -5:2007. Characterization of waste – Sampling of waste material. CEN, Brussels, Belgium.
CENELEC CLC/TS 50625-3-1:2015 Requirements for collection, logistics and processing for Waste Electrical and Electronic Equipment (WEEE) - Part 3-1: Specifications for depollution – Overview. CENELEC, Brussels, Belgium.
CENELEC CLC/TS 50625-3-1:2015 Requirements for the collection, logistics and treatment of WEEE - Part 3-1: Specification relating to depollution - General. CENELEC, Brussels, Belgium.
CEWEP 2017. Guidance document on hazard classification of MSWI bottom ash. ECN May 2017 ECN-E--17-024. Klymko T, Dijkstra JJ, van Zomeren A. 37 p. http://www.cewep.eu/wp-content/uploads/2017/09/ecn-e-17-024_guidance_document_on_eu_mswi_ba_hazard_classification.pdf
CLP 2008. Regulation (EC) n° 1272/2008 of the European parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006. 31.12.2008. Official Journal of the European Union L 353/1. Last update https://echa.europa.eu/fr/regulations/clp/legislation
EC 2008. Regulation (EC) No 850/2004 of the European parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC. Official Journal of the European Union, L 158, p. 7, 30.4.2004, last amended Commission Regulation (EU) 2016/460 of 30 March 2016, Official Journal of the European Union, L 80, p. 17, 31.3.2016. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004R0850&rid=1
ECHA 2017. Guidance on the Application of the CLP Criteria Guidance to Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures Version 5.0 July 2017. 647 p. https://echa.europa.eu/guidance-documents/guidance-on-clp
EN 12457-2:2002. Characterization of waste – Compliance test for leaching of granular waste materials and sludges – Part 2: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction). CEN, Belgium.
EN 12766-1: Petroleum products and waste oils - Determination of PCBs and related products - Part 1: Separation and determination of a selection of PCB congeners by gas chromatography (GC) with use of a capture detector Electrons (ECD). CEN, Belgium.
EN 12766-2: Petroleum products and waste oils - Determination of PCBs and related products - Part 2: Calculation of polychlorinated biphenyls (PCBs) content. CEN, Belgium.
EN 14735:2006. Characterization of waste - Preparation of waste samples for ecotoxicity tests. CEN, Belgium.
EN 14899:2015. Characterization of Waste — Sampling of waste materials — Framework for the preparation and application of a Sampling Plan. CEN, Belgium.
EN 15002:2015. Characterization of waste — Preparation of test portions from the laboratory sample. CEN, Belgium.
EN 15192:2007. Characterization of waste and soil - Determination of chromium (VI) in solid materials by alkaline digestion and ion chromatography with spectrophotometric detection. CEN, Belgium.
EN 15875:2011. Characterization of waste - Static test for the determination of the acid generation potential and the neutralization potential of sulphide waste. CEN, Belgium.
EU 2014a. Commission Decision 2014/955/EU of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council. Official Journal of the European Union. 30.12.2014. L 370/44. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0955&rid=1
EU 2014b. Commission Regulation (EU) No 1357/2014 of 18 December 2014 replacing Annex III to Directive 2008/98/EC of the European Parliament and of the Council on waste and repealing certain Directives. Official Journal of the European Union. 19.12.2014. L 365/89. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R1357&rid=1
EU 2016. ATP 9: Commission Regulation (EU) 2016/1179 of 19 July 2016 amending, for the purposes of its adaptation to technical and scientific progress, Regulation (EC) No 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and mixtures. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.195.01.0011.01.ENG&toc=OJ:L:2016:195:TOC
EU 2017a. Council Regulation (EU) 2017/997 of 8 June 2017 amending Annex III to Directive 2008/98/EC of the European Parliament and of the Council as regards the hazardous property HP 14 'Ecotoxic'. Official Journal of the European Union. 14.6.2017. L 150/1. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0997&rid=1
EU 2017b. Commission Regulation (EU) 2017/227 of 9 February 2017 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards bis(pentabromophenyl)ether. Official Journal of the European Union. 10.2.2017. L35/6. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0227&rid=1
EU 2018. European Commission. Commission notice on technical guidance on the classification of waste (2018/C 124/01). OJEU 9.4.2018. 134 p. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018XC0409(01)&qid=1530609217830&from=EN
Hennebert P, Humez N, Conche I, Bishop I, Rebischung F. 2016b. Assessment of four calculation methods proposed by the EC for waste hazard property HP 14 'Ecotoxic'. Waste Management 48 (2016) 24–33.
Hennebert P, Papin A, Padox J-M. 2013. The evaluation of an analytical protocol for the determination of substances in waste for hazard classification. Waste Management 33 (2013) 1577–1588
Hennebert P, Samaali I, Molina P. 2016a. A proposal for a test method for assessment of hazard property HP 12 ("Release of an acute toxic gas") in hazardous waste classification – Experience from 49 waste. Waste Management 58, 25–33.
Hennebert P, van der Sloot H, Rebischung F, Weltens R, Geert L, Hjelmar O. 2014. Classification of waste for hazard properties according to the recent propositions of the EC using different methods. Waste Management 34 (2014) 1739–1751.
Hennebert P. 2017a. Evaluation de la propriété de danger des déchets HP 9 'Infectieux' : Etat sommaire des méthodes existantes et propositions de méthode. Rapport INERIS DRC-16-159393-07763A. 15/06/2017. 50 p. Available upon request.
Hennebert P. 2017b. Proposal of concentration limits for determining the hazard property HP 14 for waste using ecotoxicological tests. Waste Management 74, April 2018, 74-85.

MEEM 2015. (French Ministry for Environment). Contribution of France to the « Study to assess the impacts of different classification approaches for hazard property « H14 » on selected waste streams ». Van Heeswyck E, Hennebert P, Rebischung F, Pandard P. http://ec.europa.eu/environment/waste/studies/pdf/hazard%20property%20annex%206.pdf

Norden 2015. Nordic Council of Ministers 2015. Hazardous waste classification - Amendments to the European Waste Classification regulation -what do they mean and what are the consequences? Wahlström W, Laine-Ylijoki J, Wik O, Oberender A, Hjelmar O. TemaNord 2016:519, ISSN 0908-6692, 123 p.

NRW et al 2018. Natural Resources Wales, Scottish Environment Protection Agency, Northern Ireland Environment Agency, Environment Agency 2018. Technical Guidance WM3. Waste Classification - Guidance on the classification and assessment. 181 p. https://www.gov.uk/government/publications/waste-classification-technical-guidance

Pandard P, Römbke J. 2013. Proposal for a "Harmonized" Strategy for the Assessment of the HP 14 Property, Integrated Environmental Assessment and Management — Volume 9, Number 4—pp. 665–672.

XP CEN/TS 15364:2006. Characterization of waste - Acid and basic neutralization capacity test. CEN, Belgium.

XP CEN/TS 16660:2015. Characterization of waste - Determination of reducing properties and reducing capacity. CEN, Belgium.