Joint statement against restrictions imposed by the Dutch government on the use of ferrous slags – Requirements for provisional measures not fulfilled – Appendix I

October 7th, 2025

Appendix I provides detailed information about the physicochemical characteristics of the slags such as mineral phases and structure with focus on metals such as chromium, vanadium, titanium and manganese.

In its dossier evaluation, RIVM[1],[2] denied the validity of tests and questioned the reliability of the REACH registration for ferrous slags. In one of its reports, it listed transition metals from a Tata Steel dataset (2022–2023). These elements were described as "impurities" with harmonized CMR classifications, which in principle could trigger substance classification. Elements exceeding Generic or Specific Concentration Limits (GCL/SCL) were highlighted in bold.

Comment from the REACH Ferrous Slag Consortium (RFSC):

First, it is very important to note that slags should not be considered as a 'mixture of individual chemicals'. Oxides and heavy metals in the slag do not occur in isolated form, neither as a pure metallic element nor as a potentially harmful chemical compound. Slags are not mixtures of chemical substances.

Instead, slags are complex structures consisting of individual mineral phases that interlock with each other. Exactly like natural igneous rocks, these mineral phases represent the fundamental building blocks of slags. As can be seen in Figure 1, the inner texture of slags and the interlocking of mineral phases is comparable to a natural basalt rock (Figure 1). The individual mineral phases that are commonly the constituents of BOS and EAF slags and their equivalents in natural rocks are given Table 1.

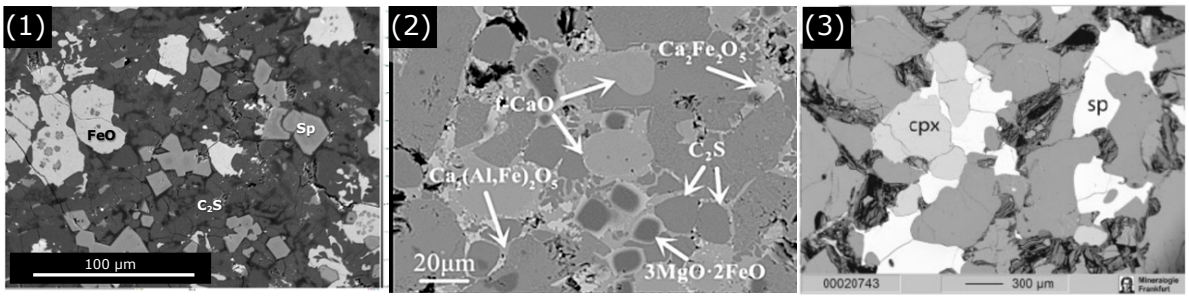

Figure 1: Backscattered electron (BSE) images of representative areas of polished thin section of (1) EAF-C (from [1]), BOS (source: Yin et al., 2018 [2]), and natural mafic mantle rock (peridotite, source: Dowes and Altherr, 2012 [3]); FeO = wuestite, Sp = spinel, C_2S = dicalsiumsilicate, cpx = clinopyroxene.

[1] https://www.rivm.nl/publicaties/milieuhygienische-kwaliteit-ld-staalslakken

[2] Advice on the classification of Slags, Steelmaking, Converter as put on the market by Tata steel IJmuiden bv (LD staalslakken), Draft Confidental, RIVM Letter report 2024- XXX

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Table 1: Typical mineral phases in BOS and EAF C slags (according to the RFSC sameness document) and their equivalents in natural rocks

		BOS	EAF C	Natural rocks
larnite, beta-dicalcium-silicate	beta-Ca_2SiO_4	x	x	Dicalcium silicate occurs in the β-modification in metamorphosed calcitic contacts in the tertiary lava pile on Mull and in the dolerite-limestone contact at Scawt Hill, both in Ireland [4]. The latter occurrence is near the town of Larne, which is why the mineral is named Larnite. The Larnite found at Scawt Hill and one found in Hatrurim, Israel, contain 0.3% and 2.7% P_2O_5, respectively, similar to the dicalcium silicate in BOS slags [5].
srebrodolskite, calcium-iron-oxide	$Ca_2Fe_2O_5$	x	x	Dicalcium ferrite is known as Srebrodolskite and is related to brownmillerite. Its occurrences are also reported from Ettringer-Bellerberg and Chelyabinsk Oblast in the Ural [6][7].
hatrurite, tricalcium-silicate	Ca_3SiO_5	x	-	Tricalciumsilcate Hatruite typically forms in metamorphosed limestone or marble It is often found in contact metamorphic environments where limestone or dolostone has been subjected to high temperatures and pressures due to nearby igneous intrusions.
spinel group minerals	$Me^{2+}Me^{3+}{}_2O_4$	x	x	Spinels occur in many igneous and metamorphic rocks. Iron and chromium spinels form well-known ore deposits, such as those at Kiruna, Sweden, and Bushveld, South Africa.
wuestite, solid solution of iron(II)-oxide with MgO and MnO	$(Fe_{1-x-y},Mg_x,Mn_y)O_z$	x	x	Wuestite crystallizes in the same crystal class as periclase, with which it forms a complete solid solution series. Wuestite occurs only under extremely reducing conditions. Meteorites and the Frohnbachtal in the Black Forest are noted as occurrences [8].
brownmillerite, calcium-aluminium-iron-oxide	Ca_2AlFeO_5	-	x	Brownmillerite can form in contacts between limestone and volcanic rock through thermal metamorphism. One occurrence is at Ettringer-Bellerberg, north of Mayen in the Eifel [9].
gehlenite, calcium-aluminium-silicate	$Ca_2Al_2SiO_7$	-	x	Gehlenite and akermanite, the end-members of the melilite solid solution series, are components of SiO_2-poor rocks that form either through the reaction of basic magmas with carbonate rocks or through the thermal metamorphism of silicate limestones [7].
bredigite, calcium-magnesium-silicate	$Ca_{14}Mg_2Si_8O_{32}$	-	x	Bredigite is a high-temperature modification of Larnite (α-dicalcium silicate) [7]. In its formula, Ca is partially replaced by Mg. The Bredigit found at Hatrurim, Israel, contains 4.6% P_2O_5.
free lime, calcium oxide	CaO	x	-	In principle, the presence of free lime in natural rocks is also possible. Due to the very rapid reaction of free lime with water to form Portlandite and the subsequent carbonation to form Calcite, such a mineral are unlikely.

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Each of these mineral phases forms a solid, crystalline structure composed of an ordered arrangement of atoms or ions. This regular structure, where atoms or ions are arranged in a repeating pattern, leads to the formation of characteristic crystal shapes. The main elements such as oxygen, silicon, aluminium, iron, calcium, and magnesium determine the fundamental properties of a mineral, including its crystal structure and physical characteristics such as hardness, colour, and density. In addition to the main elements, minerals always contain minor and trace elements (< 5 wt% and < 1 wt.-%, respectively). Depending on ion size and charge, these elements can partially replace the main elements, a phenomenon known as substitution or diadochy. Due to this property, numerous trace elements are present in the slags, which do not form independent mineral phases but integrate into the structure of the emerging mineral phases. Importantly, all mineral phases of ferrous slags can also be found in natural rocks; no new component is created during steel processing.

In conclusion, it is not reasonable to designate slag as hazardous solely based on its individual constituents, which, while potentially harmful in isolation, pose no threat when bound within mineral phases.

In the following, the individual parameters identified as concerning in the RIVM report will be addressed.

Chromium

Regarding the table on page 41 of the RIVM[3] report, it is important to clarify that it is not total chromium (Cr_total) that is mutagenic or carcinogenic, but specifically chromium in its hexavalent state (Cr-VI). But in steel slags, chromium occurs in the trivalent form. There are several reasons why chromium is unlikely to be present in the hexavalent form: steel slag is a material that, despite treatment with oxygen during production, possesses reducing properties. It contains a high content of divalent iron (and it forms in an excess of metallic iron, which has strong reducing properties). Bulk chemical analyses as well as data from the literature, including X-ray absorption near edge structure (XANES), thermodynamic modelling, and theoretical considerations, confirm that chromium in steel slags exists exclusively in the trivalent form (e.g., 10, 11, 12, 13).

Moreover, Chromium is incorporated into stable mineral phases that are resistant to weathering and not soluble in water [14]. As can be seen from results of the electron microprobe (EMP) analyses in Table 2, the mineral phase spinel contains significantly higher levels of chromium than the other mineral phases (the high standard deviation in EAF C sample 1 is due to the presence of both Cr-rich and Cr-poor spinels). Based on the results from the bulk mineral composition (quantitative X-ray diffraction and total digestion with ICP-MS measurements) and the EMP data, the relative distribution of total chromium in a sample (expressed as Cr_2O_3) across individual mineral phases can be determined. The calculated values are presented in Table 3. This analyses clearly demonstrates that spinel

[3] Advice on the classification of Slags, Steelmaking, Converter as put on the market by Tata steel IJmuiden bv (LD staalslakken), Draft Confidental, RIVM Letter report 2024- XXX

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accounts for most of the total chromium (>90 %), while the remaining 10 % is distributed among other mineral phases. Although the specific analysis in this study were conducted on EAF C slags, it is reasonable to assume a similar distribution for BOS slag, given the closely related mineralogical composition (see Table 1).

Spinel has been identified as the main carrier of chromium in several other studies (e.g., [15, 16]. The crystal structure of spinel ($Me^{2+}Me^{3+}{}_2O_4$) allows for the incorporation of trivalent or divalent metals into the lattice sites, enabling the successful integration of chromium-III. In contrast, chromium-VI cannot be incorporated into the spinel structure, ([17], see also figure 2).

Similarly, in wuestite, where a significant amount of chromium is also present (7,2 %), Cr-VI does not fit into the crystal lattice. Cr-III is more likely to be incorporated into the crystal structure as the ionic radius of Cr^{3+} (approximately 0.62–0.67 Å) is closer to that of Fe^{2+} (0.78 Å). By contrast, Cr-VI has a much smaller ionic radius (around 0.44 Å) and a significantly higher charge (+6), making its incorporation into the wuestite structure more difficult.

It can be concluded that the incorporation of most chromium into spinel and wuestite further confirms the presence of Cr-III rather than Cr-VI.

For the sake of completeness, it should be noted that high chromium contents can also be found in natural rocks. For example, Cr-rich basalts in komatiitic volcanic associations exhibit chromium concentrations exceeding 2000 ppm (i.e., > 0.2 wt.%) [18]. Similar to slags, the chromium in these rocks is bound in stable mineral phases in its trivalent form. No one would consider such rocks as containing toxic impurities.

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Table 2: Average electron microprobe analyses of individual mineral phases in two different EAF C samples (Data from [1])

EAF C sample 1								
	spinel		**ca-silikate**		**wuestite**		**gehlenite**	
	mean (n= 20)	σ	mean (n =21)	σ	mean (n=7)	σ	mean (n=9)	σ
Si	-	-	14,7	0,97	0,02	0,01	2,7	5,3
Ca	0,55	0,25	44,2	0,35	0,96	0,39	26,4	10,4
Fe2+	11,1	2,99	0,74	0,29	58,4	1,07	-	-
Fe3+	17,4	11,8	0,00	-	-	-	7,3	12,3
Al	12,0	9,54	0,15	0,37	0,35	0,10	20,4	10,3
Cr	**13,8**	22,0	**0,02**	0,02	**0,51**	0,47	**0,27**	0,75
Mg	5,9	1,84	0,07	0,04	5,0	1,36	0,98	2,7
Mn	**4,10**	1,43	**0,29**	0,12	**8,9**	0,23	**1,8**	1,6
Ti	**0,35**	0,43	**0,06**	0,04	**0,04**	0,03	**0,11**	0,14
V	**0,09**	0,17	**0,13**	0,09	**0,01**	0,01	**0,02**	0,04
P	0	0	1,46	0,43	0	0	0,56	0,18
F	0,03	0,04	0,48	0,30	0,00	0,01	0,72	0,83
O	33,3	1,0	34,8	0,19	23,60	0,27	35,93	0,15
Total	98,68		97,15		97,82		96,61	

EAF C sample 2								
	spinel		**ca-silikate**		**wuestite**		**gehlenite**	
	mean (n= 5)	σ	mean (n =9)	σ	mean (n=7)	σ	mean (n=9)	σ
Si	0,03	0,01	14,7	0,59	0,02	0,01	6,8	3,14
Ca	0,49	0,11	44,2	0,56	1,84	0,25	24,4	5,42
Fe2+	9,4	0,74	0,74	0,37	56,1	2,69	10,8	8,76
Fe3+	2,5	1,16	-	-	-	-		
Al	6,0	0,94	0,15	0,35	0,35	0,09	16,4	4,92
Cr	38,5	2,31	0,02	0,15	0,94	0,38	0,05	0,05
Mg	6,4	0,10	0,07	0,03	4,8	1,54	0,68	0,79
Mn	4,4	0,46	0,29	0,08	10,4	1,56	1,97	1,64
Ti	0,15	0,06	0,06	0,03	0,06	0,01	0,26	0,18
V	0,14	0,02	0,13	0,02	0,05	0,00	0,04	0,02
P	0,009	0,01	1,5	0,76	0,03	0,01	0,54	0,31
F	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3,14
O	32,84	0,8	35,11	0,6	23,9	0,32	36,55	0,15
Total	100,93		96,94		98,52		98,51	

n = number of analysed points on the thin section, σ = standard deviation, n.a. = not analysed

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Table 3: The relative distribution (%) of elements (oxide notation is only a convention, as all mineral phases contain oxygen) across the individual minerals in two different EAF C samples (Data from [1])

EAF sample 1									
	SiO_2	CaO	FeO/Fe_2O_3	Al_2O_3	**Cr_2O_3**	MgO	MnO	TiO_2	V_2O_5
Ca-Silikat	95	90	1,81	0,8	**0,3**	1,3	4,3	25,9	83
Wüstit	0	1,4	87,1	3,8	**7,2**	68	79	16	5,8
Spinell	0	0,2	5,5	46	**91**	25,3	12,1	44,1	7,1
Gehlenit	5,4	8,4	5,3	49	**1,8**	5,1	4,2	14,3	4,3
EAF sample 2									
Ca-Silikat	83,6	78,2	1,4	2,1	**0,5**	0,7	1,7	17,7	44,2
Wüstit	0,1	2,7	81,5	2,9	**4,5**	56,7	74,7	18,9	20,2
Spinell	0,1	0,4	9,0	25,5	**95**	38,5	16,3	22,8	27,7
Gehlenit	16,3	18,7	8,1	69,5	**0,1**	4,1	7,3	40,6	7,9

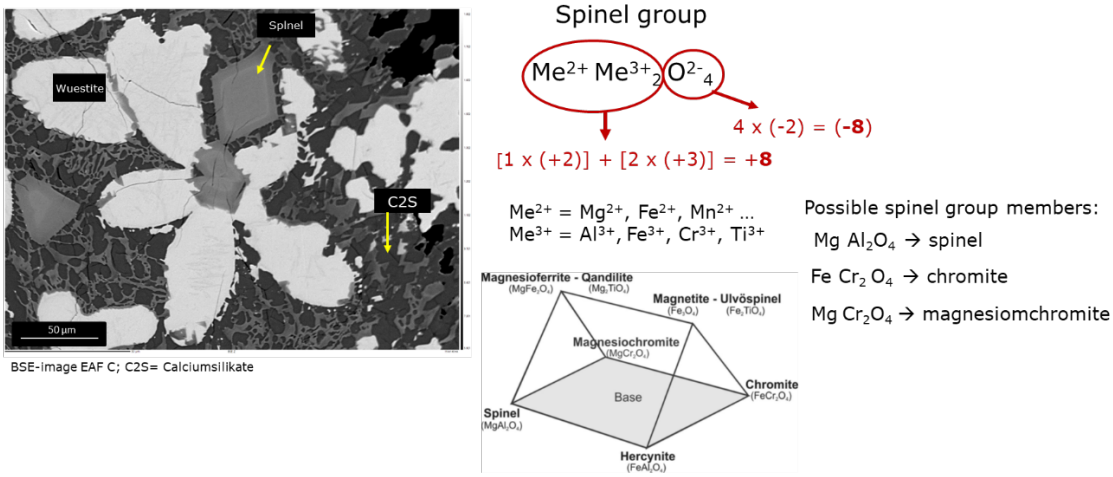

Figure 2: Backscattered electron (BSE) image of a polished thin section of an EAF C sample, showing the mineral phases wüstite and spinel in a matrix of calcium silicates (left side). The spinel group includes minerals with a cubic structure, featuring divalent and trivalent cations. The "magnetite or ulvöspinel prism" is taken from [19].

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Vanadium

Vanadium occurs in steel slag as a minor or trace element, bound within various mineral phases. As shown in Table 3, vanadium is distributed among several mineral phases, predominantly in calcium silicate, but also in spinel, wuestite, and melilite.

While vanadium pentoxide (V^{5+}) is considered hazardous, the other oxidation states, V^{4+} and V^{3+}, are far less concerning. Given the conditions present in slag melt and based on modelling and calculations [10], it is much more likely that V^{3+} and V^{4+} are the dominant valencies in the slag.

Stoichiometric considerations provide an estimate of the oxidation states in which vanadium is incorporated into the mineral phases. The ionic radius of V^{3+} (approximately 0.64 Å) is larger than that of V^{5+} (approximately 0.54 Å). This makes V^{3+} more compatible with the crystal lattice of the above-mentioned minerals, as they are better suited to accommodate the slightly larger ion. In contrast, V^{5+}, with its smaller ionic radius and higher positive charge, would be less stable in the conditions typical of steel slag. The incorporation of V^{5+} would require significant structural adjustments and additional charge-balancing mechanisms, which are not easily achieved under such conditions (e.g. [20]).

Even if the total vanadium concentration in the slag exceeds 0.1%, it does not necessarily indicate the presence of significant amounts of vanadium pentoxide. Furthermore, toxicological and ecotoxicological evaluations using slag as the substance have not demonstrated any of the hazardous properties listed in Annex III of the EU Waste Framework Directive (WFD), known as Hazardous Properties (HP). No classification under the CLP Regulation [21] is required.

Additionally, it is important to note that Regulation (EU) 2017/997 [22] stresses that assessments based on ecotoxicity tests should take precedence over alternative approaches, such as summing the individual ecotoxicity classifications of the constituents.

Titanium

On 23 November 2022, the EU Court of Justice ruled that the classification of titanium dioxide (TiO_2) as a Category 2 carcinogen was unlawful, overturning this classification. As a result, titanium dioxide is no longer classified as a hazardous substance in the EU, and the associated regulatory obligations will no longer apply in the future.

Additionally, titanium, in its metallic form, has never been classified as carcinogenic. The concerns were specific to titanium dioxide (TiO_2), which is not present in steel slags.

Steels slags may contain minor (e.g., < 1 wt.-%) concentrations of titanium which is often found as trace element incorporated in other minerals as magnetite (Fe_3O_4) partly substitution the lattice of iron.

Importantly, steel slags **do not** contain free TiO_2 in the form of the mineral phases rutile or anatase. Both **rutile** and **anatase** are naturally occurring polymorphs of titanium dioxide, sharing the same chemical composition but differing in their crystal structures.

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Rutile is the more stable and denser form with a compact tetragonal structure, while anatase is less stable, has a more open tetragonal structure, and can convert to rutile at higher temperatures.

Manganese

Manganese is also present as a minor or trace element within various mineral phases. As shown in Table 3, manganese is distributed among several mineral phases, predominantly within iron-rich phases such as wuestite.

It is also important to note that manganese (Mn) and iron (Fe) behave similarly from a chemical perspective due to their comparable ionic sizes and oxidation states. Both Mn^{2+} and Fe^{2+}, as well as Mn^{3+} and Fe^{3+}, have similar ionic radii (0.80 Å and 0.74 Å for Mn^{2+} and Fe^{2+}, respectively), which allows them to readily substitute for each other in mineral structures [23]. This chemical similarity extends to their roles in slag and mineral phases, where both elements often participate in the same crystal lattices, such as in magnetite, where manganese can partially replace iron. Consequently, the behavior of manganese in steel slags is analogous to that of iron, and their combined presence does not result in the formation of hazardous compounds.

Toxic manganese compounds, such as MnO_2, $MnSO_4$, $MnCl_2$, and $Mn(CH_3COO)_2$, are not present in steel slags. Their occurrence can be ruled out based on mineralogical and chemical analyses, as well as logical considerations. Additionally, the study in [24] concluded that the absence of systemic manganese delivery to the striatum or lungs from EAF slag indicates that incidental ingestion of manganese from EAF slag is unlikely to pose a health hazard. These findings are also applicable to BOS slags, due to their similar mineralogical properties and behaviour.

[1] Konzeptentwicklung zur Reduzierung der V-Auslaugung aus EOS. Inno-Kom Research Project 49VF210006

[2] Yin et. al. (2018) Stabilization of free CaO in molten BOF slag by addition of silica at high temperature. Metall. Res. Technol. 115, 414 (2018)

[3] Dowes H., Altherr R. (2012) Oxidation State of the Lithospheric Mantle below the Massif Central, France. Journal of Petrology 55, 2457-2480

[4] Tiley C.E. et.al.: The occurrence of an orthorhombic high-temperature form of Ca2SiO4 (bredigite) in the Scawt Hill contactzone and as a constituent of slags. Mineralogical Magazine, Vol. XXVIII, No. 200 (1948)

[5] Römpp Chemie Lexikon, Georg Thieme Verlag, Stuttgart

[6] Hentschel, G.: Mayenit, 12CaO •7Al2O3, und Brownmillerit, 2CaO •(Al, Fe)2O3, zwei neue Minerale in den Kalksteineinschlüssen der Lava des Ettringer Bellerberges. Neues Jahrbuch für Mineralogie, Monatshefte (1964) S. 22, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart

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[7] Chesnokov, B., Bazhenova, L.: Zap. Vses. Mineral. O-va, Bd. 114 (1985) S. 195

[8] Walenta, K.: Die Mineralien des Schwarzwaldes, Verlag Weise, München, 1992

[9] Galuskin (2012) A reinvestigation of mayenite from the type locality, the Ettringer Bellerberg volcano near Mayen, Eifel district, Germany. Mineralogical Magazine 73 (3), 707-716

[10] Cheremisina, E., Schenk, J.: Chromium stability in steel slags. Steel Research Int. 88 (2017) 11.

[11] Lumpkin, G. R.: Crystal chemistry and durability of the spinel structure type in natural systems. Progress in Nuclear Energy 38 (2001) No. 3-13, 447-454.

[12] Chaurand, P. et al.: Environmental impacts on steel slag reused in road construction: A crystallographic and molecular (XANES) approach. Journal of Hazardous Materials (2007) Bd. B 139, 537-542.

[13] Chaurand, P. et al.: Environmental impact of steel slag reused as aggregates in road manufacturing: Molecular mechansim of chromium and vanadium Release. X-Ray Absorption Fine Structure XAF13: 13th International Conference, 9-14 July 2006.

[14] Geiseler, J., Kühn, M., Mudersbach, D.: Untersuchungen zur metallurgischen Behandlung von Schlacken aus der RSH-Stahlproduktion. Report des FEhS–Instituts für Baustoff-Forschung 6 (1999) 1, 9-11.

[15] Li, J. et al.; Effect of basicity on precipitation of spinel crystals in a CaO-SiO2-MgO-Cr2O3-FeO System. High Temp. Mater. Proc 38 (2019), 867-872.

[16] Chaurand, P. et. al.: Speciation of Cr and V within BOF steel slag reused in road constructions. Journal of Geochemical Exploration 88 (2006), 10-14.

[17] Deer, W. A., Howie, R. A., Zussmann, J.: An introduction to the rock-forming minerals. 3rd ed., London, 2013, ISBN 978-0903056-33-5.

[18] Halkoaho T. et al. (2000) Exceptionally Cr-rich basalts in the komatiitic volcanic association of the Archaean Kuhmo greenstone belt, eastern Finland. Mineraogy and Petrology 70, 105-120

[19] Ferracutti et al. (2014) Determination of the spinel group end-members based on electron microprobe analyses. Mineralogy and Petrology. 109, 153-160.

[20] Wunderlich et al. (2021) Investigation on Vanadium Chemistry in Basic-Oxygen-Furnace 8BOS) Slags – A first Approach. Metals 2021, 11, 1869

[21] Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006.

[22] Regulation (EU) 2017/997 of the Council of 8 June 2017 amending Annex III of Directive 2008/98/EC of the European Parliament and of the Council concerning hazard property HP 14 "ecotoxic”.

[23] Adriano, D.C. (2001). Manganese. In: Trace Elements in Terrestrial Environments. Springer, New York, NY.

[24] Proctor et al. (2023) Manganese relative oral bioavailability in electric arc furnace steel slag is influenced by high iron content and low bioaccessibility. Toxicological Sciences, 2023, 193(2), 234–243

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