

Determination of trace elements in aqua regia and nitric acid digests by atomic absorption spectrometry - graphite furnace

1 Scope

This Horizontal Standard includes principles and procedures for the determination of trace metals in aqua regia and nitric acid digests of sludge, soil and treated biowaste and neighbouring samples, using atomic absorption spectrometry with electrothermal atomization in a graphite furnace. The method is applicable for determination of low concentrations of the following elements: Ag, Cd, Co, Cr, Cu, Ni, Pb, Sb, Tl, V.

The method detection limit for each element depends on the sample matrix as well as of the instrument, the type of atomizer and the use of chemical modifiers. For water samples with a simple matrix (i.e. low concentration of dissolved solids and particles), the method detection limits will be close to instrument detection limits. In digests containing higher concentrations of dissolved solids, interference effects may lead to an increase in the method detection limit. The values of Table 1 should at least be obtainable, using a 20 µl sample volume.

Table 1 - Approximate characteristic masses, instrument detection limits and optimum working ranges for water samples using a 20 µl sample volume.

Element	Characteristic mass (m_0) ^a , pg	Detection limit ^b , µg/l	Optimum working range ^c , µg/l
Ag	1,5	0,2	1 - 10
Cd	0,7	0,1	0,4 - 4
Co	10	1	6 - 60
Cr	3	0,5	2 - 20
Cu	5 ^d	0,5	3 - 30
Ni	13	1	7 - 70
Pb	15	1	10 - 100
Sb	20	1	10 - 100
Tl	10 ^d	1	6 - 60
V	35	2	20 - 200

^a The characteristic mass (m_0) of an element is the mass in picograms, corresponding to a signal of 0,0044 seconds (s), using the integrated absorbance (peak area) for evaluation.

^b The detection limits are calculated as 3 times the standard deviation of repeated measurements of a blank solution.

^c The optimum working range is defined as the concentration range that corresponds to integrated absorbance readings between 0,05 and 0,5 s.

^d If Zeeman effect background correction is used, the m_0 value will be higher.

2 Normative references

This Horizontal Standard incorporates by dated or undated references, provisions from other publications. These normative references are cited at the appropriate places in the text and the

publications are listed hereafter. For dated references, subsequent amendment to or revisions of these publications apply to this Horizontal Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

ISO 3696:1987	Water for analytical laboratory use. Specification and test methods.
EN xxx: 200y (Hor.)	Chemical analyses - Digestion of soil, sludge, biowaste and waste for the extraction of <i>aqua regia</i> soluble elements.
EN xxx: 200y (Hor.)	Chemical analyses - Digestion of soil, sludge, biowaste and waste for the extraction of nitric acid soluble fraction of trace elements.
EN-ISO 15587-1:2003	Water Quality – Digestion for the determination of selected elements in water – Part 1: Aqua regia digestion.
EN-ISO 15587-1:2003	Water Quality – Digestion for the determination of selected elements in water – Part 1: Nitric acid digestion.

3 Principle

In electrothermal atomization atomic absorption spectrometry, discrete sample aliquots are dispensed into a graphite tube (of which there are several types), which can be heated to over 2800 °C very rapidly and in a controlled manner. By increasing the temperature stepwise, the processes of drying, thermal decomposition of the matrix and thermal dissociation into free atoms occur. Atomic absorption spectrometry is based on the ability of free atoms to absorb light. A light source emits light specific for a certain element (or elements). When the light beam passes through the atom cloud in the heated graphite furnace, the light is selectively absorbed by atoms of the chosen element(s). The decrease in light intensity is measured with a detector at a specific wavelength. The concentration of an element in the sample is determined by comparing the absorbance of the sample with the absorbance of calibration solutions. The signal-peak produced is, under optimum conditions, sharp and symmetrical, and of narrow half-width. The height of the peak is, for most elements, proportional to the concentration of the element in solution, although for certain elements it is preferable to work from peak area. The measurements are made at the wavelengths given in Table 2.

Table 2. General conditions for electrothermal atomic absorption spectrometry

Element	Wavelength	Atomization conditions	Recommended background correction technique
Silver	328,1	No platform	Zeeman, deuterium
Cadmium	228,8	Platform recommended	Zeeman, deuterium
Chromium	357,9	No platform	Zeeman or Smith-Hieftje
Cobalt	240,7	No platform	Zeeman, deuterium
Copper	324,8	Platform recommended	Zeeman or Smith-Hieftje
Lead	217,0	Platform recommended	Zeeman, deuterium
Nickel	232,0	No platform	Zeeman, deuterium
Antimony	217,6	No platform	Zeeman, deuterium
Thallium	276,8	No platform	Zeeman, deuterium
Vanadium	318,4	No platform	Zeeman, deuterium

If necessary, interferences may be overcome by adding a matrix modifier to the samples before analysis, or by performing the calibration with standard addition technique.

The results are given as the mass of analyte (micrograms or milligrams) per kilogram of dried materials in sediments and soils.

4 Interferences

Sample solutions of waste waters and digestions of sediments and soils, may contain large amounts of substances that may affect the results. High concentrations of chloride may cause low results, because the volatility of many elements is increased and analyte loss may occur during the pyrolysis step. Matrix effects may be overcome, partially or completely, by optimization of the temperature programme, the use of pyrolytically coated tubes or platforms, the use of chemical modifiers, the standard addition technique and the use of background correction.

5 Reagents

All reagents shall be of recognized analytical grade. Use deionized water or water distilled from all-glass apparatus, conforming to grade 1 of ISO 3696 ($\leq 0,01$ mS/m, or better).

The water used for blank determinations and for preparing reagents and standard solutions shall have a concentration of the element to be determined that is negligible compared with the lowest concentration of that element in the sample solutions.

5.1 Hydrochloric acid, 30 % Suprapur; $\rho \sim 1,15$ g/ml

The same batch of hydrochloric acid shall be used throughout the procedure.

5.2 Nitric acid, 65 % Suprapur; $\rho \sim 1,39$ g/ml

The same batch of nitric acid shall be used throughout the procedure.

5.3 Nitric acid, diluted 1 + 3 (V/V)

Add 250 ml of nitric acid (5.3) to 500 ml of water in a 1000 ml volumetric flask and fill to the mark with water.

5.4 Aqua regia, diluted $\sim 1 + 3$

Dilute 210 ml of hydrochloric acid (5.1) and 70 ml of nitric acid (5.2) with about 500 ml of water in a 1000 ml volumetric flask, and dilute to the mark.

5.5 Stock solutions

Both single-element stock solutions and multi-element stock solutions with adequate specification, stating the acid used and the preparation technique, are commercially available. These solutions are considered to be stable for more than one year, but in reference to guaranteed stability, the recommendations of the manufacturer should be considered.

Alternatively, the stock solutions may be prepared as indicated in table A1 in Annex A.

5.6 Standard solutions

Use the same acid as the digested samples when preparing the standard and the calibration solutions.

5.6.1 Standard solution corresponding to 10 mg/l of element

Pipette 10,00 ml of the actual element stock solution (5.5) into a 1000 ml volumetric flask. Add 20 ml of nitric acid (5.3) or 20 ml of aqua regia (5.4), fill to the mark with water and mix well.

5.6.2 Standard solution corresponding to 0,1 mg/l of element

Pipette 5,00 ml of the element standard solution (5.6.1) into a 500 ml volumetric flask. Add 10 ml of nitric acid (5.3) or 10 ml of aqua regia (5.4), fill to the mark with water and mix well. Prepare this solution on the day of use.

5.7 Calibration solutions

Before each batch of determinations, prepare, from the standard solutions of each element (5.6.1 or 5.6.2), at least four calibration solutions covering the range of concentrations to be determined, the optimum working range being indicated in table 1. Calibration solutions shall be prepared on the day of use. Use the set of standard solutions containing the same acid as the digested samples.

5.8 Blank calibration solutions

Prepare a blank calibration solution in the same way as the calibration solutions, but add no standard solution. Use a 100 ml volumetric flask. Add acid in correspondence to the samples that the solution will be analysed together with. Cool if necessary and dilute to volume with water.

5.9 Palladium nitrate / magnesium nitrate modifier

$\text{Pd}(\text{NO}_3)_2$ solution is commercially available (10 g/l). Dissolve 0,259 g of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ in 100 ml of water. Mix the palladium nitrate solution with twice as much magnesium nitrate solution. 10 μl of the mixed solution is equal to 15 μg Pd and 10 μg $\text{Mg}(\text{NO}_3)_2$. The mixture is also commercially available. Prepare the solution freshly every month.

5.10 Magnesium nitrate modifier

Dissolve 0,865 g $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ in 100 ml of water. 10 μl of this solution is equal to 50 μg $\text{Mg}(\text{NO}_3)_2$.

5.11 Ammonium dihydrogen phosphate modifier

Dissolve 2,0 g of $\text{NH}_4\text{H}_2\text{PO}_4$ in 100 ml of water. 10 μl of this solution is equal to 200 μg $\text{NH}_4\text{H}_2\text{PO}_4$.

5.12 Ammonium dihydrogen phosphate / magnesium nitrate modifier

Dissolve 2,0 g of $\text{NH}_4\text{H}_2\text{PO}_4$ and 0,173 g of $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ in 100 ml of water. 10 μl of this solution is equal to 200 μg $\text{NH}_4\text{H}_2\text{PO}_4$ and 10 μg $\text{Mg}(\text{NO}_3)_2$.

5.13 Nickel modifier

Dissolve 0,200 g of nickel powder in 1 ml concentrated nitric acid (5.2) and dilute to 100 ml with water. 10 μl of this solution is equal to 20 μg Ni. Solutions of $\text{Ni}(\text{NO}_3)_2$ are also commercially available.

5.14 Purge gas

Argon, Ar (> 99,99 %).

6 Apparatus

6.1 Usual laboratory apparatus

All glass or plastic ware shall be cleaned carefully before trace element determinations, e.g. by immersion in warm 5 % (V/V) aqueous nitric acid solution for a minimum of 6 hours, followed by rinsing with water before use. The nitric acid shall be replaced each week.

NOTE It has been found convenient to to keep separate sets of glass or plastic ware for the determinations given in this Horizontal Standard, in order to reduce the possibility of within-laboratory contamination. Similarly, it can be convenient to carry out the acid cleaning step overnight. Certain kinds of plastic are effected by nitric acid, so care should be taken in the choice of plastic. Because of the high sensitivity of electrothermal atomic absorption spectrometry, stringent precautions should be taken to clean all glass or plastic ware and avoid contamination of sample, standard and calibration solutions from foreign material and dust from the laboratory atmosphere.

6.2 Atomic absorption spectrometer

This shall be equipped with an electrothermal atomizer, the necessary hollow cathod lamps or electrodeless discharge lamps appropriate to the element of interest and operated at a current recommended for the lamp by the instrument manufacturer, an automatic background correction device, and a computerized read-out or a high speed chart recorder. Background correction shall be used with electrothermal atomic absorption spectrometry, the minimum acceptable technical specification (below 350 nm wavelength) of which is that based on deuterium.

NOTE Deuterium background correction is appropriate for cadmium, zinc and lead, if the limited application of deuterium background correction for some instruments to about 0,6 to 0,8 absorbance is not exceeded. Smith-Hieftje or Zeeman background correction is required for all elements if the background signal is high. To increase the analyte-to-background-signal ratio, application of a graphite tube with a pyrolytic platform together with matrix modifiers such as diammonium hydrogen phosphate $(\text{NH}_4)_2\text{HPO}_4$, reduced palladium or other, plus peak integration read-out, are recommended for samples with high acid and matrix load. Pyrolytic graphite has the additional advantage that carry-over from sample to sample is likely to be greatly reduced for most elements, in comparison with non-pyrolytic graphite. Users of this

Horizontal Standard should not assume that the routine instrumental settings recommended by the manufacturers will necessarily give the best results with complex matrices such as those dealt with in this Horizontal Standard. Careful development of temperature programmes is essential.

6.3 Automated sample introduction system

Depending on the concentration levels to be determined, new autosampler cups may be cleaned with dilute acid. For example clean the vessels with nitric acid, about 1 mol/l, and rinse with water. The autosampler system shall be capable of delivering fixed volumes up to 70 µl.

6.4 Graphite tubes

Pyrolytically coated graphite tubes with platforms are preferably used for high and medium volatile elements, while elements of low volatility should be atomized from the wall. Provided satisfactory results are achieved, manufacturers recommendations regarding the use of graphite tubes and platforms should be followed.

7 Chemical modification

Chemical modifiers are used to overcome spectral and/or non-spectral interferences in a sample (matrix effects). By measuring a sample with and without addition of an analyte, and compare the recovery of the analyte with a calibration standard, the existence of a non-spectral interference is often recognized. In order to ascertain that the modification works, the same procedure is repeated with the addition of a chosen chemical modifier.

In general, the aim of chemical modification is to allow a pyrolysis temperature that is high enough to remove the bulk of concomitants before the atomization step. The combination of Pd and Mg(NO₃)₂ is regarded as a “universal” modifier that is used for a lot of elements. The combination of Pd and a reducing agent, like ascorbic acid, is sometimes used instead of Pd/Mg(NO₃)₂. The background absorption tends to be high with Mg(NO₃)₂. Other modifiers are also used. Some of them (e.g. Ni compounds) may be disadvantageous, because they contain

Table 3. Recommended chemical modifiers.

Element	Chemical modifiers (5.9 to 5.13)	Amounts, µg ^a
Ag	Pd + Mg(NO ₃) ₂ or NH ₄ H ₂ PO ₄	15 + 10 or 200
Cd	Pd + Mg(NO ₃) ₂ or NH ₄ H ₂ PO ₄ + Mg(NO ₃) ₂	15 + 10 or 200 + 10
Co	Mg(NO ₃) ₂	50
Cr	Mg(NO ₃) ₂	50
Cu	Pd + Mg(NO ₃) ₂	15 + 10
Ni	Mg(NO ₃) ₂	50
Pb	Pd + Mg(NO ₃) ₂ or NH ₄ H ₂ PO ₄ + Mg(NO ₃) ₂	15 + 10 or 200 + 10
Sb	Pd + Mg(NO ₃) ₂ or Ni (as nitrate)	15 + 10 or 20
Tl	Pd + Mg(NO ₃) ₂	15 + 10
V	No modifier required	

^a These amounts are only recommendations. Significantly lower amounts may be required in some atomizers. See also recommendations from instrument manufacturers.

elements that are frequently determined with the same equipment and will cause contamination of the furnace. In table 3 some recommendations of chemical modifiers are given for the elements in this standard. Other chemical modifiers may be used if they show consistent results.

If chemical modifiers are used, add them both to test samples, reagent blank solutions, blank test solutions, calibration solutions, and blank calibration solutions. To achieve the recommended amounts in the table 3, 10 µl of modifier solution shall be added. Preferably inject the modifier solution with the autosampler directly into the atomizer after the sample is delivered.

8 Determination

Examples of how to program the graphite furnace are given in annex B.

A temperature programme for the graphite furnace usually includes four steps: drying, pyrolysis, atomization and cleaning. Preferably, as a start, use the temperatures and times recommended by the manufacturer. Interrupt the argon flow during the atomization step. Always use background correction.

Alternative wavelengths (with different sensitivities) may be used. E.g. for lead, the wavelength 217,0 nm may be used, where the sensitivity is about twice of that at 283,3 nm. However, the noise is higher and the risk for interferences is greater. In case of high concentrations a wavelength with lower sensitivity may be used. For evaluation the integrated absorbance (peak area) is recommended.

8.1 Test portion

The solid samples shall be extracted with aqua regia or nitric acid in accordance with EN-xxx or EN-yyy, respectively. To cover the calibration range of the very sensitive electrothermal absorption method and to protect the graphite tubes from high acid concentrations, it is recommended to dilute the sample solutions 1 + 3 with water, as follows. Pipette 25,00 ml of each sample solution into a 100 ml volumetric flask and fill to the mark with water.

8.2 Blank test solution

The blank test solution should be prepared at the same time as the extraction with aqua regia or nitric acid was performed, using cleaned quartz sand instead of the soil sample and following the same procedure, using the same quantities of all reagents for the determination. To prepare the diluted blank test solutions 1 + 3, pipette 25,00 ml of the above solution into a 100 ml volumetric flask and fill to the mark with water.

8.3 Procedure

Set up the instrument parameters and align the electrothermal atomizer according to the manufacturer's instructions to take full advantage of the background correction system. Set up the sampler similarly. Determine the optimum electrothermal atomizer parameters for the particular type of atomizer and sample volume (up to 70 µl) as recommended by the instrument manufacturer to cover the optimal working range. Set the instrument baseline to

zero. Check the zero stability within the atomization system by running the pre-set heating programme for blank firing of the graphite atomizer. Check the lack of spectral interferences by running real sample solutions with standard additions. Repeat the blank firing to ensure baseline stability.

Using the autosampler, inject into the atomiser the predetermined volume (up to 70 μl) of each of the diluted test solutions. Add a fixed volume of modifier solution, atomize and note the instrument response. If possible, sort the test solutions into groups of three or four with similar concentrations of the analyte, starting with the lowest. Be careful to note any memory effects caused by particular samples, especially at high analyte levels.

Using an autosampler, inject a fixed volume of solution. Add a fixed volume of modifier solution and atomize the diluted blank calibration solution (5.3 or 5.4), the calibration solutions (5.7), the diluted blank test solution (8.2) and the diluted test solutions (8.1) in order of increasing instrument response. If the peak height (or peak area) of the test portion exceeds the value of the highest calibration solution, a smaller volume of the test portion shall be used.

Atomize each solution at least twice and, if the reproducibility is acceptable according to the quality control system in use in the laboratory, average the readings. Check the instrument again for absence of memory effects, especially at high analyte levels, by running the blank firing programme after high readings. Reset the baseline to zero if necessary.

If an unknown type of sample is to be handled, each element concentration shall be determined by means of the standard addition method. If the analytical results according to the standard addition method and calibration curve are equal, the calibration curve method can be applied.

NOTE The reproducibility of the instrument readings expressed as an absolute difference, coefficient of variation, or a standard deviation, will vary depending on the concentration of the element in the extracts.

9 Calibration

9.1 Standard calibration technique

Perform the calibration with a blank calibration solution (5.8) and four equidistant calibration solutions (5.7) for an appropriate concentration range. It should be stressed that the linearity of the calibration curve is often limited.

Correct the absorbance values of the calibration solutions by subtracting the absorbance value of the blank calibration solution. For plotting a calibration curve or for calculation of the calibration function, use the resulting values together with the analyte concentrations of the calibration solutions.

9.2 Standard addition technique

To reduce the effect of non-spectral interferences, if chemical modification is not used or does not eliminate matrix effects, the standard addition technique may be applied provided the calibration curve is linear in the absorbance range used. The standard addition technique

cannot be used to correct for spectral interferences, such as unspecific background absorption, and shall not be used if interferences are changing the signal with a factor of more than three.

Transfer equal volumes of the test sample to three vessels (e.g. autosampler cups). Add a small amount of standard solution to two of the vessels, calculated that the resulting concentration in the samples will be respectively about 100 % and 200 % higher than what is expected in the original sample. Add an equal amount of water to the third vessel. Mix the solutions well. Measure the integrated absorbance of each solution, and the plot a diagram where the concentration added is given on the abscissa and the measured absorbance on the ordinate. Determine the analyte concentration in the reagent blank solution or blank test solution in the same way.

10 Calculation of results

Read the analyte concentrations of the test sample solutions and blank test solution from the calibration graph or calculate them from the calibration function. Correct the analyte concentrations of the test sample solutions by subtracting the analyte concentration of the test blank solution.

Calculate the analyte content of the test samples, when the determination is performed on a dried material, from the formulae

$$w_{(M)} = c \cdot f \cdot V / m$$

or when the determination is performed on wet sample

$$w_{(M)} = c \cdot f \cdot V \cdot 100 / (i \cdot k)$$

where

- $w_{(M)}$ is the mass fraction of the element M in the sample, in milligrams per kilogram;
- c is the concentration of the element, in micrograms per liter, of the digested and diluted sample, corrected for the blank test solution;
- f is the dilution factor of the diluted test portion (7.1);
- V is the volume, in litres, of the test portion taken for the analysis, e.g. 0,1 litre in accordance with ISO 11466;
- h is the mass of the dried sample, in milligrams;
- i is the mass of the wet sample, in milligrams;
- k is the content of dried material in the wet sample, in %.

11 Test report

The results are given in $\mu\text{g}/\text{kg}$ or mg/kg for the solid samples. Results for test samples where no detectable signal could be obtained are given as < “the detection limit”.

The measurement uncertainty reported for the results should reflect the results from the quality control measures and incorporate the deviation between the individual readings for the sample in question. In general, values shall not be expressed to a greater degree of accuracy

than two significant figures. The rounding of values will depend on the statistics of the quality control procedures mentioned earlier, and the requirements of the analysis. For results below 1 mg/kg, experience shows that greater accuracy than one significant figure is rarely achieved.

Example: $w(\text{Co}) = 2,5 \text{ mg/kg}$
 $w(\text{Co}) = 0,3 \text{ mg/kg}$

In addition to the results, the report should also contain:

- a) a reference to this EN standard;
- b) complete identification of the sample;
- c) information of possible sample pre-treatment;
- d) information about digestion method applied;
- e) date of sampling and determination;
- f) information about other factors that may have affected the results.

12 Performance characteristics of the method

An interlaboratory test has to be performed to yield precision data.

Annex A (Informative)

Preparation of stock solutions, 1000 mg/l

The following procedures for preparation of stock solutions are taken from U.S. Environmental Protection Agency, Method 200.9 – Determination of Trace Elements by Stabilized Temperature Graphite Furnace Atomic Absorption, Rev. 2.2, 1994, and Method 200.7 - Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma-Atomic Emission Spectrometry, Rev. 4.4, 1994 (V). All salts should be dried for one hour at 105 °C, unless otherwise is specified.

Table A.1 – Amount of metals and metal salts for preparation of stock solutions

Element	Compound	Formulae	Amount, g
Ag	Metal	Ag	1,000
Cd	Metal ^a	Cd	1,000
Co	Metal ^a	Co	1,000
Cr	Chromium trioxide	CrO ₃	1,923
Cu	Metal ^b	Cu	1,000
Ni	Metal	Ni	1,000
Pb	Lead nitrate	Pb(NO ₃) ₂	1,599
Sb	Metal powder	Sb	1,000
Tl	Thallium nitrate	TlNO ₃	1,303
V	Metal ^a	V	1,000

^a Acid cleaned with (1 + 9) HNO₃. ^b Acid cleaned with (1 + 1) HCl.

Ag stock solution: Dissolve the metal in 80 ml (1 + 1) HNO₃ with heating to effect dissolution. Cool and dilute to volume with water in a 1000 ml volumetric flask. Store the solution in amberbottle or wrap bottle completely with aluminium foil to protect from light.

Cd, Co, Cu, and V stock solution: Dissolve the metal in 50 ml (1 + 1) HNO₃ with heating if necessary to effect dissolution. Cool and dilute to volume with water in a 1000 ml volumetric flask.

Cr stock solution: Dissolve the metal compound in 120 ml (1 + 5) HNO₃. Dilute to volume with water in a 1000 ml volumetric flask.

Ni stock solution: Dissolve the metal in 20 ml hot concentrated HNO₃. Cool and dilute to volume with water in a 1000 ml volumetric flask.

Pb stock solution: Dissolve the metal compound in minimum amount of (1 + 1) HNO₃. Add 20 ml (1 + 1) HNO₃ and dilute to volume with water in a 1000 ml volumetric flask.

Sb stock solution: Dissolve the metal powder in 20 ml (1 + 1) HNO₃ and 10 ml concentrated HCl. Add 100 ml water and 1,50 g tartaric acid. Warm solution slightly to effect complete dissolution. Cool and dilute to volume with water in a 1000 ml volumetric flask.

Tl stock solution: Dissolve the metal compound in water. Add 10 ml concentrated HNO₃. Dilute to volume with water in a 1000 ml volumetric flask.

Annex B (Informative)
Examples of instrumental parameter settings

There may be great differences between instruments from different manufacturers, and between old and new models. It is recommended to use the temperatures proposed by the manufacturers as a start.

Element	Wave-length nm	Slit width nm	Pyrolysis temperature °C		Atomization temperature °C	
			Without modifier	With modifier ^a	Without modifier	With modifier ^a
Ag	328,1	0,7	650	1000 / 650	1600	2200 / 2200
Cd	228,8	0,7	300	900 / 900	1250	1100 / 1800
Cr	357,9	0,7	1050	1650	2300	2600
Co	240,7	0,2	1100	1400	2200	2400
Cu	324,8	0,7	1100	1100	2300	2600
Pb	217,0	0,7	600	1200 / 600	1500	2000 / 1900
Ni	232,0	0,2	1100	1400	2400	2400
Sb	217,6	0,7	900	1200 / 1100	1900	1900 / 2400
Tl	276,8	0,7	600	1000	1350	1650
V	318,4	0,7	1400	-	2650	-

^a The alternate temperature values are for the cases where two alternative chemical modifiers are recommended