Cobalt

Application	Determination in blood
Analytical principle	Electrothermal atomic absorption spectrometry
Completed in	October 1985

Summary

With this procedure cobalt may be determined reliably in whole blood by means of electrothermal atomic absorption spectrometry. The accuracy of the method is confirmed by comparison with a differential pulse polarography method which is independent at every step. The procedure is suitable for the biological monitoring of persons occupationally exposed to cobalt metal, its alloys or compounds. The detection limit, however, is not low enough to determine concentrations of this essential metal in the physiological range.

The blood samples are diluted eight times and, without further processing, are subjected directly to a charring program with a number of temperature steps in the graphite furnace. The quantitative evaluation is carried out using the standard addition procedure.

Within-series imprecision:	Standard deviation (rel.)	s_w = 1.1–6.8 %
	Prognostic range	u = 2.5–15.4 %
	At concentrations ranging from 1.9–11.4 µg cobalt per litre blood and where n = 10 determinations	
Between-day imprecision:	Standard deviation (rel.)	s = 6.2 %
	Prognostic range	u = 14.0 %
	At a concentration of 11.3 µg cobalt per litre blood and where n = 10 days	
Imprecision of duplicate analyses:	Standard deviation (rel.)	s_d = 2.8 %
	At concentrations ranging from < 1 – 31.1 µg cobalt per litre blood and where n = 12 duplicate analyses	
Inaccuracy:	Estimated by comparison with an differential pulse polarography method which is independent at every step	
	Recovery rate	r = 90 –113 %
Detection limit:	1 µg Cobalt per litre blood	

Cobalt

Cobalt (atomic mass 58.93 g/mol, mp 1495 °C, bp 2870 °C) is a steel-grey, magnetic metal of the iron group. It occurs in compounds in oxidation states II and III. The earth's crust contains 0.001 % cobalt. Cobalt occurs naturally mostly in the form of sulfides, arsenides and carbonates. The element is obtained, almost as a by-product, during the smelting of copper ores containing cobalt and nickel.

Cobalt is used in the production of various alloys and special steels which are characterized by temperature stability, corrosion resistance, durability and ferromagnetic properties [1]. A large proportion of the cobalt produced is used in the manufacture of hard metals which consist of metal carbides, usually tungsten carbide, with cobalt as binding agent. These particularly durable hard metals are suitable for applications such as special tools and endoprostheses. Cobalt compounds have a variety of applications e.g. colouring in ceramic products, siccatives in paints and varnishes, as catalysts in organic syntheses, etc.

Although the annual production figures and use of cobalt appear relatively moderate – in the Federal Republic of Germany about 2000 t, in the United States of America 8000 t – the wide variety of applications of the metal are indicative of its wide industrial and consequently environmental distribution. Therefore it may be assumed that many people handle cobalt at work and so their health may be affected by the metal. According to a survey carried out by the Berufsgenossenschaft der chemischen Industrie (Professional Association of the German Chemical Industry) 2300 persons in 70 places of work are exposed to cobalt in the Federal Republic of Germany [2]. Moreover, it is believed that in the United States of America about 1.4 million people are involved in the handling of cobalt, cobalt oxides and cobalt-containing siccatives [3]. The monitoring of the health of persons exposed to cobalt is thus of considerable interest to occupational medicine. Interest is focussed on the effect of cobalt on the lungs as well as on the question of the mutagenic and carcinogenic effects of this element and its compounds. In addition, it is suspected that cobalt may have been the cause of cardiomyopathy which was observed in individuals after excessive indulgence in beer containing cobalt salts to stabilize the froth. Larger doses of cobalt salts induce an increase in the erythrocyte count as well as the haemoglobin level in blood. These erythropoietic effects have been made use of at times in the treatment of anaemia. The time-dependent and dose-dependent increase in the blood sugar levels which occurred in the course of this treatment is indicative of an effect of the metal on the pancreas. Finally it should be mentioned that repeated administration of cobalt has resulted in hypothyroidism which can be accounted for by the reduced iodine uptake induced by cobalt.

A number of monographs and reviews contain information as to the toxicity of cobalt [3–9].

Preventive measures against occupationally induced illness caused by cobalt and its compounds are concerned these days mainly with lung fibrosis, which is observed in particular in connection with the production and processing of hard metals. They are also concerned with the potential mutagenic and carcinogenic effects of cobalt and its compounds, although these effects have yet to be demonstrated. In the Federal Republic of Germany, cobalt and its compounds are included in the MAK Values List (1986) as sub-

stances which have proved to be unmistakably carcinogenic in animal experimentation (Section III A 2). The Technische Richtkonzentrationen (Technical Guiding Concentrations) established by the Ausschuß für Gefahrstoffe beim Bundesministerium für Arbeit und Sozialordnung (Committee for Hazardous Working Materials in the Federal Ministry of Labor and Social Affairs) are 0.5 mg/m^3 for the production of cobalt powder and catalysts and 0.1 mg/m^3 for other installations.

Cobalt is an essential trace element. It is a constituent of vitamin B_{12} which is involved in the formation of the red pigment in blood. A person must take in about 3 µg vitamin B_{12} each day to avoid the deficiency symptoms which lead to so-called pernicious anaemia. This requirement for vitamin B_{12} is covered by the amount of cobalt ingested daily with food and should be between 40 and 50 µg [10]. The majority of the cobalt taken in with food, however, is excreted unchanged in the urine.

Toxic symptoms are induced by cobalt only on ingestion of about 100 times the amount normally eaten in food. The effects on thyroid and blood count described above are registered after doses above 30 mg per day.

According to the most recent atomic absorption spectrometric analyses, the cobalt concentrations in the blood and urine of normal individuals are lower than previously assumed [11–14]. 95 % of all urine levels measured in a group of 79 persons who were not involved with cobalt at work were below 0.86 µg/L [15]. Analytical procedural difficulties make it impossible at present to quote a normal cobalt level for blood. The majority of the values cited in the literature are in the range between 0.1 and 146 µg cobalt per litre blood [11] and are considered to be too high.

Occupational exposure to cobalt leads to an increase of the cobalt concentrations in blood and urine which are proportionally related to each other. According to the literature the urine cobalt level seems to be between 7.5 and 10 times that in blood [16–18]. Both matrices are therefore in principle suitable for occupational medical screening of persons exposed to cobalt at work. It is important to note that whole blood is used for determining the cobalt level because the proportion of the total cobalt present in the serum is interindividually variable [19].

As our picture of the relationship between the internal cobalt levels and their effects on health is still far from complete, it is at present not possible to state a safe level for cobalt in blood and urine. Were it to be demonstrated that cobalt is carcinogenic for man as well as animals, then such levels could not be determined on principle. Nevertheless, it is possible to estimate from the relationship between the work place levels and those in biological material what level of internal cobalt stress arises under the conditions given by the Technical Guiding Concentrations (Technische Richtkonzentrationen). Such biological correlations have been evaluated by the Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe (Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area) [20]. Thus a cobalt concentration of 100 or 500 µg/m^3 in the air is equivalent to a blood cobalt level of 5 or 25 µg/L, respectively. Under these exposure conditions urine cobalt concentrations of 60 or 300 µg/L, respectively, are to be expected.

Author: *J. Angerer*
Examiners: *M. Fleischer, K. H. Schaller*

Cobalt

Application	Determination in blood
Analytical principle	Electrothermal atomic absorption spectrometry
Completed in	October 1985

Contents

1 General Principles

Cobalt is determined directly in whole blood without any further sample treatment by means of electrothermal atomic absorption spectrometry. Interference from the biological matrix is eliminated by diluting the blood eight times and by using an optimized multistage charring program. The quantitative evaluation is carried out using the standard addition procedure.

2 Equipment, chemicals and solutions

2.1 Equipment

Atomic absorption spectrometer with background correction at 240.7 nm
Graphite furnace
Chart recorder
Monoelement cobalt hollow cathode lamp
Graphite tube, pyrolytically coated
Roller mixer (e.g. from Denley)
Vortex mixer (e.g. from Cenco)
Disposable polyethylene tubes with stoppers (approx. 12 ml)
50, 100, 500 and 1000 mL Volumetric flasks
Automatic pipettes, adjustable between 20–200 and 200–1000 µL (e.g. Pipetman from Gilson, obtainable from Abimed)
Disposable syringes containing anticoagulant (e.g. K-EDTA Monovetten®, Sarstedt, Nümbrecht, FRG)

2.2 Chemicals

Cobalt standard (e.g. Fixanal from Riedel-de Haën) containing 0.1 g cobalt as cobalt chloride
65 % Nitric acid (e.g. Suprapur from Merck)
Triton X-100 (e.g. from Merck)
1-Octanol
Ultrapure water (ASTM type 1) or double-distilled water
Argon (99.998 %)

2.3 Solutions

Aqueous Triton X-100 solution (approx. 0.01 %):
About 50 mL ultrapure water is pipetted into a 100 ml volumetric flask. 0.01 mL Triton X-100, warmed to about 40 °C, is then added. After thorough mixing the flask is filled to the mark with ultrapure water.

0.01 M Nitric acid:
0.36 mL 65 % nitric acid is pipetted into about 200 mL ultrapure water in a 500 mL volumetric flask. After thorough mixing, the flask is filled to the mark with ultrapure water.

1 M Nitric acid (for cleaning glassware and tubes):
72 mL 65 % nitric acid is pipetted into a 1000 mL volumetric flask containing about 400 mL ultrapure water. After thorough mixing, the flask is filled to the mark with ultrapure water.

2.4 Calibration standards

Stock solution:
The cobalt standard containing 0.1 g Co is diluted to the mark with ultrapure water in a 1000 mL volumetric flask (0.1 g/L).

The calibration standards are prepared by diluting the stock solution with 0.01 M nitric acid. They must be freshly prepared for each analytical series.

Volume of stock solution µL	Final volume of calibration standard mL	Concentration of calibration standard µg/L	Designation of calibration standard
25	50	50	I
62.5	50	125	II
100	50	200	III

3 Specimen collection and sample preparation

The blood specimens are drawn from the arm vein using disposable syringes and transferred to disposable plastic tubes which contain an anticoagulant (e.g. potassium EDTA). Alternatively, commercially available syringes containing anticoagulant may be used. The specimens are mixed thoroughly to prevent clotting.

In this form the specimens may be dispatched and if necessary stored for up to seven days in the refrigerator. For longer storage the specimens should be deep frozen. Before processing the specimens are allowed to come to room temperature, preferably by taking them out of the refrigerator on the evening previous to analysis. They are then homogenized for at least 30 min on a roller mixer and the aliquots for analysis taken immediately.

Disposable polyethylene tubes are used for sample processing after they have been rinsed first with 1 M nitric acid, then three times with ultrapure water and dried at room temperature. 850 µL of the 0.01 % Triton X-100 solution is pipetted into each of four such prepared tubes and mixed with 40 µL 1-octanol. To each tube 125 µL of the homogenized blood specimen is added using an automatic pipette and allowing the blood to run down the wall of the tube immediately above the surface of the liquid. Then the pipette tip is rinsed by drawing up liquid from the tube. The samples are mixed for 20 s on the vortex mixer. 25 µL 0.01 M nitric acid with or without the appropriate amount of cobalt is added to each tube as shown in the following table:

Sample designation	0.01 % Triton soln.	1-Octanol	Blood	0.01 M Nitric acid	Calibration standards 50 µg/L I	125 µg/L II	200 µg/L III	Spiked cobalt concentration expressed in terms of blood volumne used
	µL	µL	µL	µL	µL	µL	µL	µg/L
Sample without standard	850	40	125	25	–	–	–	–
+ standard I	850	40	125	–	25	–	–	10
+ standard II	850	40	125	–	–	25	–	25
+ standard III	850	40	125	–	–	–	25	40

After adding the calibration standards the samples are mixed again for 20 s on the vortex mixer.

At least one sample blank is assayed with each set of samples. For this purpose ultrapure water is used instead of blood.

4 Operational parameters for atomic absorption spectrometry

Atomic absorption spectrometer:

Wavelength:	240.7 nm
Background correction:	Deuterium lamp
Spectral slit width:	0.2 nm
Lamp current:	According to manufacturer's instructions
Analytical determination:	Maximum extinction recorded during the atomization step

The temperature program shown in the following table is only intended as a guide. The optimization of the program must be carried out for each individual instrument.

Temperature-time-program:

Analytical step	Step duration Ramp time s	Hold time s	Temperature °C
Drying	10	25	100
Charring I	15	15	350
Charring II	20	15	500
Charring III	5	15	1000
Atomization	0	10	2650, 30 mL/min
Heating	1	2	2700

Inert gas:	Argon
Injected volume:	25 µL

5 Analytical determination

25 µL of each sample solution is injected into the graphite tube and the extinction of the atomization peak is recorded. The value for the unspiked sample should not be more than 0.1 (equivalent to about 30 µg cobalt per litre blood). If the concentration is more than 20 µg/L (with an extinction of about 0.065 for the unspiked sample) a smaller volume of blood (e.g. 50 µL) must be used for the analysis.

6 Calibration and calculation of the analytical result

The cobalt concentration of the blood sample is determined graphically. The extinction of the reagent blank is subtracted from the extinction values of the unspiked sample as well as from the three spiked samples which are then plotted as a function of the added cobalt concentration in blood. The intercept of the resulting straight line with the concentration axis gives the cobalt concentration in µg/L (see Fig. 1). Any dilution of the blood sample before treatment must be allowed for arithmetically. The calibration curve was shown to be linear for up to about a concentration of 90 µg/L.

7 Standardization and quality control

Quality control of the analytical results is carried out as stipulated by Article TRgA 410 (Regulation 410 of the German Code on Hazardous Working Materials) [21]. Until standards become commercially available, they must be prepared in the laboratory.

8 Reliability of the method

8.1 Precision

For the determination of the within-series imprecision, pooled blood was spiked with three different cobalt concentrations in the range from 2–10 µg/L. Each sample was analysed ten times (see Tab. 1). The relative standard deviation varied from 1.1 to 6.8 % and the corresponding prognostic ranges from u = 2.5 to 15.4 %.

The between-day imprecision was determined using whole blood to which 10 µg cobalt per litre had been added. The results of analyses on ten different days yielded a standard deviation of s = 6.2 % (see Tab. 1).

In addition the precision of the procedure was determined using blood samples from twelve persons occupationally exposed to cobalt. The cobalt levels ranged from < 1 to 31.1 µg/L, on average 10.8 µg/L. The samples were all analysed in duplicate. A standard

deviation may be determined from the differences between duplicate analyses [22]. In our case a value of 0.3 µg/L was obtained. If this is expressed in terms of the average concentration of the samples it is equivalent to a variation of 2.8 %.

8.2 Accuracy

Using blood samples from persons occupationally exposed to cobalt the accuracy of the procedure described here was tested by comparison with a second method. This procedure, using a differential pulse polarography determination after ashing the blood samples, was independent of our procedure at every step. As shown in Fig. 2, the results of the two procedures are highly correlated (r = 0.986). The slope of 0.95 indicates that the two methods produce results which may be taken as identical within the respective error limits.

Recovery experiments were also carried out. This procedure is the same as for calibration (standard addition) and serves only as an internal laboratory check. The samples are prepared as described in Section 8.1. Since the cobalt concentration in the pooled blood used was below the detection limit, the recovery could not be determined accurately. There are, however, various indications that the cobalt concentration in the blood of normal individuals is very probably less than 0.1 µg/L. Therefore this value was used in the calculation of the recovery rates, which were found to range from r = 90 to 113 %. The individual results are given in Tab. 1.

8.3 Detection limit

With the method described here, blood concentrations above 1 µg/L may be determined with adequate precision.

8.4 Sources of error

The method described here is relatively resistant to interference. If cleaning and rinsing of tubes is carried out as described, the risk of contamination is small compared to that in assays of other metals (e.g. nickel).

9 Discussion of the method

With the method described here [24], cobalt may be determined directly in whole blood by means of electrothermal atomic absorption spectrometry.

The cobalt level may be determined without interference because of the considerable dilution of the biological matrix and the three temperature steps in the charring program. The dilution step results in a drastic reduction in interference from the matrix. By using a

multistage temperature-time program it is possible to control charring and evaporation of the organic components so that losses of cobalt do not occur. This prevents uncontrolled smoke formation which, in our experience, can carry part of the cobalt mechanically out of the sample and so out of the assay system.

The final temperature during the charring program, 1000 °C, is high enough to ash or evaporate organic components which could interfere with the atomic absorption spectrometric determination without danger of losses of cobalt.

Gas stop conditions during the atomization step result in a slight increase in sensitivity but, at the same time, in a markedly higher background. For this reason an internal gas flow of 30 mL/min is used.

The results of the precision and recovery determinations demonstrate that the method yields analytically valid results for cobalt concentrations which are higher than the normal levels. The between-day imprecision of about 6 % fulfills the requirements of statistical quality control. The good reliability of the method may be seen also in the results of the duplicate analyses of blood samples from occupationally exposed persons. It may thus be concluded that interindividual differences in blood composition appear to have no disadvantageous effects on the reliability of the procedure.

The accuracy of the method was checked and confirmed with an independent differential pulse polarography method [23]. Since the latter determination is preceded by a total ashing of the blood, these results demonstrate additionally that the direct method presented here determines all the cobalt in the blood samples independent of its chemical form.

Under the conditions described here, cobalt concentrations of about 1 µg/L lead to a measured extinction of about 0.004, which is normally given as the detection limit of electrothermal atomic absorption spectrometric methods.

The results demonstrate that the method introduced here is superior in terms of sensitivity and analytical reliability to older methods of blood plasma analysis [25, 26]. In a procedure published by *Delves* et al. [27], whole blood is diluted in the ratio 1:2 with a mixture of hydrochloric acid and ammonium dihydrogen phosphate and then analysed by means of ETAAS. Residual matrix components are diminished by flushing with oxygen gas during the charring step in the graphite tube. Usually this results in a drastically shortened life span for the graphite tube and a rapid reduction in sensitivity of the cobalt assay.

Deproteinization procedures, such as have proved of value for the determination of, e.g., cadmium in blood [28], are not successful in the case of cobalt. With a method described by *Christensen* et al. [14], in which whole blood is deproteinized with nitric acid and the mixture then warmed, only an average of 30 % of the actual cobalt content is determined [29]. This may be accounted for by the fact that a fraction of the cobalt is bound to plasma proteins and a further part to haemoglobin [19].

To summarize, the cobalt content of blood may be determined reliably with the method described here. This applies for cobalt concentrations which are increased above the physiological range e.g. as a result of occupational exposure. The physiological concentration range, which, according to our results, lies under the detection limit obtained here (1 µg/L), cannot be determined with this method.

Instruments used:
Atomic absorption spectrometer 4000 with graphite furnace HGA 500 from Perkin Elmer

10 References

[1] *W. Betteridge:* Cobalt and its alloys. John Wiley & Sons, New York 1982.
[2] *Berufsgenossenschaft der chemischen Industrie:* Ergebnisse der Erfassung von gefährlichen Arbeitsstoffen. Sichere Chemiearbeit 8/1982, p. 60–62.
[3] *NIOSH:* Occupational hazard assessment/Criteria for controlling occupational exposure to cobalt. DHHS Publication No. 82-107, Cincinnati 1981.
[4] *C. G. Elinder and L. Friberg:* Cobalt. In: *L. Friberg, G. F. Nordberg,* and *B. Vouk* (eds.): Handbook on the toxicology of metals. Elsevier, Amsterdam 1980, p. 399–410.
[5] *M. D. Kipling:* Cobalt. In: *H. A. Waldron* (ed.): Metals in the environment. Academic Press 1980, p. 133–153.
[6] *G. N. Schrauzer:* Cobalt. In: *E. Merian* (ed.): Metalle in der Umwelt. Verlag Chemie, Weinheim 1984, p. 425–433.
[7] *I.* C. *Smith* and *B. L. Carson:* Trace metals in the environment. Vol. 6, Cobalt. Ann Arbor Science, Ann Arbor 1981.
[8] *H. E. Stokinger:* Cobalt. In: *G. D. Clayton* and *F. E. Clayton* (eds.): Patty's industrial hygiene and toxicology. Vol. II A, John Wiley & Sons, New York 1981, p. 1605–1619.
[9] *J. Angerer* and *R. Heinrich:* Cobalt. In: *H. G. Seiler* and *H. Sigel:* Handbook on the toxicity of inorganic compounds. Marcel Dekker, New York, in press.
[10] *R. Schelenz:* Dietary intake of 25 elements by man estimated by neutron activation analysis. J. Radioanal. Chem. *37,* 539–548 (1977).
[11] *J. Versieck* and *R. Cornells:* Normal levels of trace elements in human blood plasma or serum. Anal. Chim. Acta *116,* 217–254 (1980).
[12] *V. V. Lidums:* Determination of cobalt in blood and urine by electrothermal atomic absorption spectrometry. At. Absorp. Newslett. *18,* 71–72 (1979).
[13] *M. Hartung, K. H. Schaller, M. Kentner, D. Weltle,* and *H. Valentin:* Untersuchungen zur Cobalt-Belastung in verschiedenen Gewerbezweigen. Arbeitsmed. Sozialmed. Präventivmed. *18,* 73–75(1983).
[14] *J. M. Christensen, S. Mikkelsen,* and *A. Skov:* A direct determination of cobalt in blood and urine by Zeeman atomic absorption spectrophotometry. In: Chemical toxicology and clinical chemistry of metals. IUPAC 1983.
[15] *R. Heinrich* and *J. Angerer:* Cobalt und Nickel in biologischem Material – Analysenverfahren für physiologische und expositionsbedingte Konzentrationen. In: *B. Welz* (ed.): Fortschritte in der atomabsorptionsspektrometrischen Spurenanalytik. Vol. 2, VCH Verlagsgesellschaft, Weinheim 1986, p. 159–170.
[16] *J. Angerer, R. Heinrich, F. X. Felixberger, D. Szadkowski,* and *G. Lehnert:* Cobalt-Aufnahme und -Ausscheidung bei beruflicher Exposition. In: *H. Konietzko* and *F. Schuckmann:* Bericht über die 24. Jahrestagung der Deutschen Gesellschaft für Arbeitsmedizin e. V., Mainz 2. – 5. Mai 1984, Gentner Verlag, Stuttgart 1984, p. 293–296.
[17] *J. Angerer, R. Heinrich, D. Szadkowski,* and *G. Lehnert:* Occupational exposure to cobalt powder and salts – biological monitoring and health effects. In: *T. D. Lekkas* (ed.): Heavy Metals in the Environment. Proceedings Int. Conf. Athens, September 1985, Vol. 2, p. 11–13.

[18] *Y. Ichikawa, Y. Kusaka,* and *S. Goto:* Biological monitoring of cobalt exposure, based on cobalt concentrations in blood and urine. Int. Arch. Occup. Environ. Health *55,* 269–276 (1985).
[19] *E. Schumacher-Wittkopf:* Characterization of cobalt-binding proteins in occupational cobalt exposure. Toxicol. Environ. Chem. *8,* 1–9 (1984).
[20] *J. Angerer:* Cobalt. In: *D. Henschler* and *G. Lehnert* (eds.): Biologische Arbeitsstoff-Toleranz-Werte (BAT-Werte). Arbeitsmedizinisch-toxikologische Begründungen. Deutsche Forschungsgemeinschaft, Verlag Chemie, Weinheim, 3rd issue 1986.
[21] TRgA 410: Statistische Qualitätssicherung. Ausgabe April 1979. In: *W. Weinman* and *H.-P. Thomas:* Gefahrstoffverordnung Teil 2: Technische Regeln (TRGS) und ergänzende Bestimmungen zur Verordnung über gefährliche Stoffe. Carl Heymanns Verlag K. G., Köln, 10th issue, 1984.
[22] see p. 8, Vol. 1 of this series, 1985.
[23] *R. Heinrich* and *J. Angerer:* Determination of cobalt in biological materials by voltammetry and electrothermal atomic absorption spectrometry. Int. J. Environ. Anal. Chem. *16,* 305–314 (1984).
[24] *J. Angerer* and *R. Heinrich:* Bestimmung von Cobalt in Blut mit Hilfe der elektrothermalen Atomabsorptionsspektrometrie. Fresenius' Z. Anal. Chem. *318,* 37–40(1984).
[25] *F. J. M. J. Maessen, F. D. Posma,* and *J. Balke:* Direct determination of gold, cobalt and lithium in blood plasma using the mini-Massmann carbon rod atomizer. Anal. Chem. *46,* 1445–1449(1974).
[26] *R. A. A. Muzzarelli* and *R. Rocchetti:* Atomic-absorption determination of manganese, cobalt and copper in whole blood and serum with a graphite atomizer. Talanta *22,* 683–685 (1975).
[27] *H. T. Delves, R. Mensikov,* and *L. Hinks:* Direct determination of cobalt in whole-blood by electrothermal atomization and atomic absorption spectroscopy. In: *P. Brätter* and *P. Schramel* (eds.): Trace Element – Analytical Chemistry in Medicine and Biology. Vol. 2, Walter de Gruyter & Co., Berlin – New York 1983, p. 1123–1127.
[28] *M. Stoeppler, J. Angerer, M. Fleischer,* and *K. H. Schaller:* Cadmium. Vol. 1 of this series, 1985 p. 79–92.
[29] *R. Heinrich* and *J. Angerer:* ETAAS-determination of cobalt in whole blood – comparison of direct and deproteinization procedures. Fresenius' Z. Anal. Chem. *322,* 772–774 (1985).

Author: *J. Angerer*
Examiners: *M. Fleischer, K. H. Schaller*

Tab. 1: Imprecision and recovery rates determined using human blood samples spiked with cobalt.

Imprecision	*n*	Expected value (Reagent blank + added conc.)	Measured value $\bar{x}$	*s*	*u*	Recovery rate
		µg/L	µg/L	%	%	%
Series	10	0.1* + 2.0	1.9	6.8	15.4	90
Series	10	0.1* + 5.0	5.7	4.2	9.5	112
Series	10	0.1* + 10.0	11.4	1.1	2.5	113
Day to day	10	0.1* + 10.0	11.3	6.2	14.0	112

* The cobalt concentration of the unspiked blood sample was set at 0.1 µg/L for the calculation of the recovery rates.

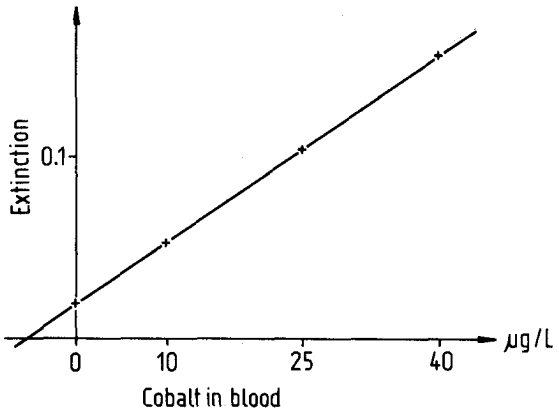

Fig. 1: Example of a linear standard addition graph for the atomic absorption spectrometric determination of cobalt in blood using a pyrolytically coated graphite furnace.

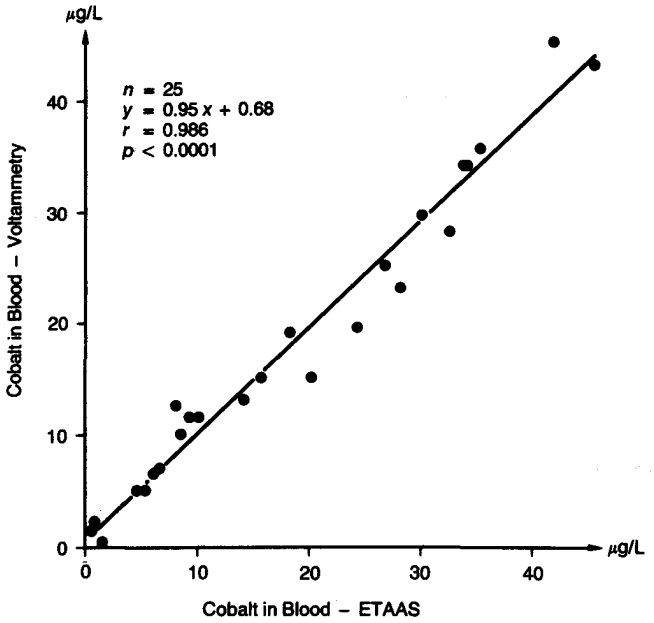

Fig. 2: Correlation curve for the parallel analysis of 25 blood samples from persons exposed to cobalt using the direct method described here and a differential pulse polarography procedure [23] which was independent at every step.

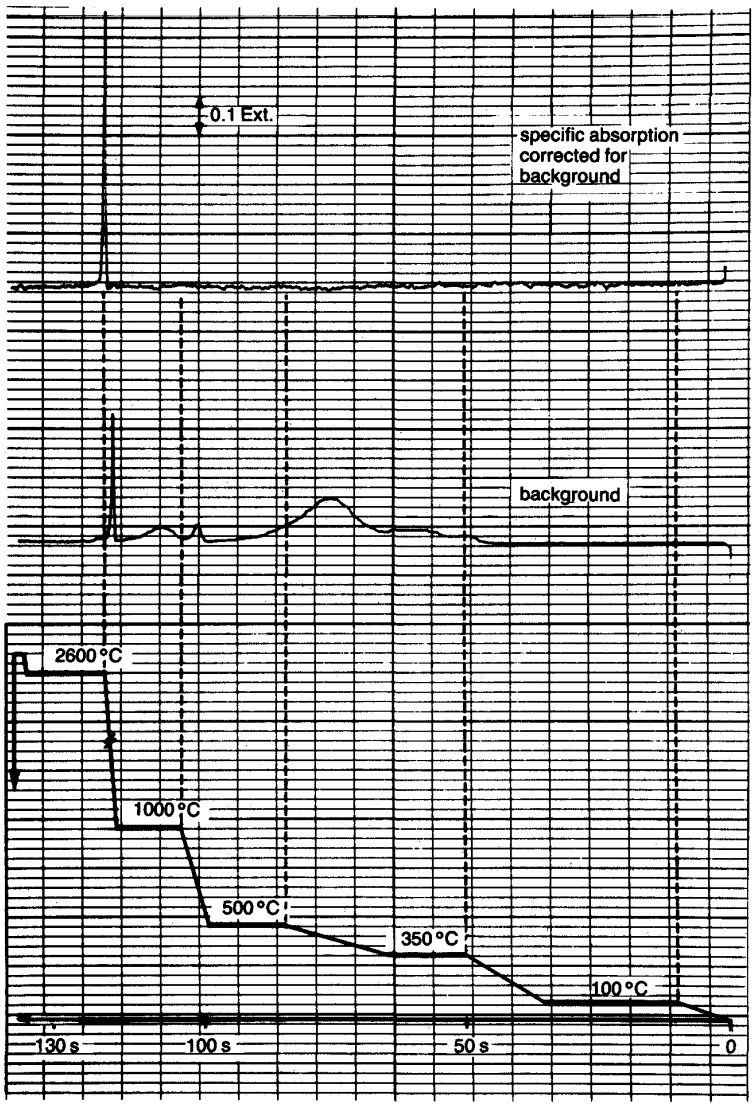

Fig. 3: Time course of the background signal and the corrected specific absorption during the direct determination of cobalt in whole blood.