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SERIES L: CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Measurement methods to characterize rare metals in information and communication technology goods

Recommendation ITU-T L.1101

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Measurement methods to characterize rare metals in information and communication technology goods

Summary

Information and communication technology (ICT) goods, which consist of many parts and modules, are comprised of relatively small quantities of rare metals and larger quantities of major materials (e.g., iron, nonferrous metals, plastics, glasses, and engineering ceramics). They are usually produced through complex production procedures. To achieve successful recycling systems, the rare metals information provided by manufacturers should be accurate. However, many measurement and characterization methods may be used to obtain information on rare metals for elements of ICT goods. Each method has its own intrinsic advantages and disadvantages in the analysis of the information of such elements.

The element separation capabilities and quantitative resolutions differ according to the measurement methods used and there are no standardized measurement methods to define the quantities and qualities of rare metals. However, IEC 62321 provides some guidelines for X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) measurement methods to perform qualitative and quantitative analysis of unknown samples and harmful materials.

Based on the guidelines of IEC 62321, Recommendation ITU-T L.1101 provides reference characterization procedures for efficient recycling of rare metals by using XRF and ICP-MS measurement methods.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T L.1101	2014-03-22	5	11.1002/1000/12134

Keywords

Climate change, element measurement, ICT goods, quantitative resolution, rare metals.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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Measurement methods to characterize rare metals in information and communication technology goods

1 Scope

This Recommendation explains the measurement methods for rare metals contained in Information and Communication Technology (ICT) goods. The measurement method may affect the interpretation of the results.

This Recommendation specifies measurement methods to determine types and associated quantities of the rare metals of ICT goods.

This Recommendation covers:

- an overview of rare metals measurements;
- the reference rare metals recycling procedure; and
- recommended measurement methods of rare metals of ICT goods.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1100] Recommendation ITU-T L.1100 (2012), *Procedure for recycling rare metals in information and communication technology goods*.

[IEC 62321] IEC 62321 ed 1.0 (2008), *Electrotechnical Products – Determination of levels of six regulated substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ethers)*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 information and communication technology (ICT) goods [b-ITU-T L.1400]: The tangible products deriving from, or making use, of technologies devoted to, or concerned with (a) the study and application of data and the processing thereof; i.e., the automatic acquisition, storage, manipulation (including transformation), management, movement, control, display, switching, interchange, transmission or reception of a diversity of data; (b) the development and use of the hardware, software, and procedures associated with this delivery; and (c) the representation, transfer, interpretation, and processing of data among persons, places, and machines, noting that the meaning assigned to the data must be preserved during these operations.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

At%	Atomic per-cent
AED	Atomic Emission Detector
AES	Auger Electron Spectroscopy
CD-ROM	Compact Disk − Read-Only Memory
EDS	Energy Dispersive X-ray Spectroscopy
FTIR	Fourier Transform Infrared spectroscopy
HF	Hydrofluoric
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometer
ICT	Information and Communication Technology
LA	Laser Ablation
LA-ICPMS	Laser Ablation Inductively Coupled Plasma Mass Spectrometry
LCD	Liquid Crystal Display
LEXES	Low Energy X-ray Emission Spectrometry
PC	Personal Computer
PCB	Printed Circuit Board
ppm	parts per million
ptt	parts per trillion
RBS	Rutherford Backscattering Spectrometry
SEM	Scanning Electron Microscopy
SIMS	Secondary Ion Mass Spectrometry
STEM	Scanning Transmission Electron Microscopy
TOF-SIMS	Time-of-flight Secondary Ion Mass Spectrometry
TXRF	Total reflection X-Ray Fluorescence
Wt%	weight per-cent
XPS/ESCA	X-ray Photoelectron Spectroscopy/Electron Spectroscopy for Chemical Analysis
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
XRR	X-Ray Reflectivity

5 Introduction of rare metal measurement in ICT goods

5.1 Overview of rare metals in ICT goods

Rare metals are essential to obtain high performance and high functionality in ICT goods. As global awareness on environmental problems is on the rise, the concern in the ICT industry on the recycling of electric and electronic goods is increasing. Nowadays, there is an increased emphasis on the recycling of rare metals in mobile phones, personal computers (PCs) and other ICT goods. In addition, much research on recycling methods of rare metals is being promoted.

Each country has different industrial structures and security situations, and the definition of rare metals is not exactly the same in each country because geographic distribution of rare metals is different. Nevertheless, there are some elements commonly agreed as rare metals, reported in the following:

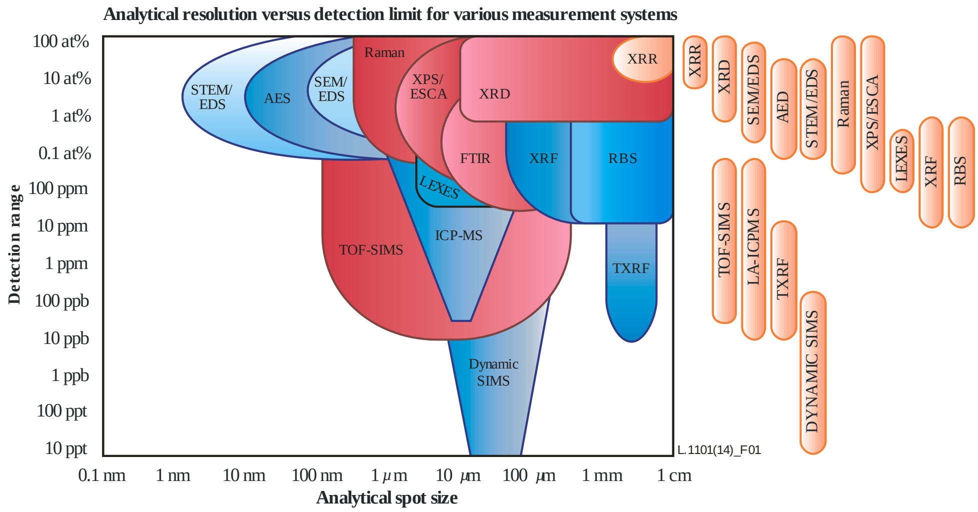
- Alkaline earth metal: Li, Ca, Be, Sr, Ba
- Metalloid: Ge, Bi, Se, Te
- Iron group: Co
- Boron group: B, Ga, In, Tl, Cd
- High fusion point metal: Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Re
- Rare earth: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Sc, Y
- Platinum group: Ru, Rh, Pd, Os, Ir, Pt

For example, rare metals such as indium (In), yttrium (Y), gallium (Ga) and arsenic (As) are widely used in ICT goods such as smartphones, laptops, etc. For more information, see [ITU-T L.1100].

5.2 Rare metal element measurement methods

For successful recycling, producers are required to provide detailed information on rare metals to recyclers. The provided information should be accurate for effective recycling. However, many measurement and characterization methods may be used to obtain this information on elements (rare metals). Moreover, each method has its intrinsic advantages and disadvantages for the analysis of these elements. Element separation abilities and quantitative resolutions are divergent in different measurement methods.

Figure 1 depicts an analytical resolution diagram for various element measurement systems. Each measurement system has a different analytical spot size and detection quantity range. If a producer applies a non-standard measurement method and system to ICT goods, rare metal information based on [ITU-T L.1100] may be incorrect. Moreover, it is hard to distinguish rare earth elements contained in rare metals because they have similar chemical properties. The development of standard measurement methods to characterize rare metals in ICT goods is urgently required. Hence, this Recommendation provides two recommended measurement methods in clause 6.2 to characterize rare metals.



NOTE 1 – Raman refers to Raman spectroscopy.
NOTE 2 – Refer to clause 4 for other acronyms.

Figure 1 – Analytical resolution diagram showing element measurement systems
(Reproduced with the kind permission of EAG [b-EAG])

Usually measurement of rare metal elements is performed by a combination of different ways of measurement methods (e.g., TOF-SIMS, XRD and XRF).

1) TOF-SIMS (Time-of-flight secondary ion mass spectrometry)

TOF-SIMS uses a pulsed primary ion beam to desorb and ionize species from a sample surface. The resulting secondary ions are accelerated into a mass spectrometer, where they are mass analysed by measuring their time-of-flight from the sample surface to the detector. TOF-SIMS provides spectroscopy for characterization of chemical composition, designed to determine the distribution of chemical species, and depth profiling for thin film characterization.

2) XRD (X-ray diffraction)

XRD is based on the principle that different structural materials distinguish different diffraction angles and intensities. XRD is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions, as such XRD analysis methods are used for obtaining information on the structure of crystalline materials.

3) XRF (X-ray fluorescence)

XRF analysis has an advantage of supporting the measurement of high-content major metals. XRF uses the emission of characteristic secondary X-rays from a material that has been excited by bombardment with high-energy X-rays or gamma rays. The XRF has been widely used for elemental and chemical analyses. This method can identify every metal element and measure its amount at percentage levels. The weights of metals in electric wires, metal-plastic composites, magnets, and vibrators are recorded and these components are then subjected to XRF to obtain rare metal information. The advantages of XRF measurements are that they can measure elemental metal, plastic, solution or powder samples without pre-treatment and they can have multi-element measurement capability. They can also minimize the analytical error margin.

5.3 Rare metal quantity measurement methods

Usually measurement of rare metal quantity is performed through a combination of different methods (e.g., ICP-OES, AES and, ICP-MS).

1) ICP-OES (Inductively coupled plasma optical emission spectrometer)

ICP-OES is used to obtain a measurable strength of a spectral line and is an analytical technique to detect trace metals.

NOTE – The trace metals are metals in extremely small quantities.

2) AES (Auger electron spectroscopy)

AES is a common technique used specifically in the analysis of surfaces and is based on the analysis of Auger electrons emitted from an excited atom by the relaxation process. This measurement method is used to analyse the state of the elemental analysis of the solid surface by measuring the energy of the Auger electron.

3) ICP-MS (Inductively coupled plasma mass spectrometry)

ICP-MS can detect metals and several non-metals by ionizing the sample with inductively coupled plasma and then using a mass spectrometer to separate and quantify those ions. It can measure the composition and content of rare metals. The advantages of ICP-MS are: multi-element simultaneous analysis, less interference effects than those of other measurement methods, high speed of automated analysis, analysis of a wide range of concentrations, higher detection limits (ppt, i.e., part-per-trillion), and direct measurement of isotopes.

6 Measurement methods to characterize rare metals in ICT goods

6.1 Recycling procedures – Flow chart

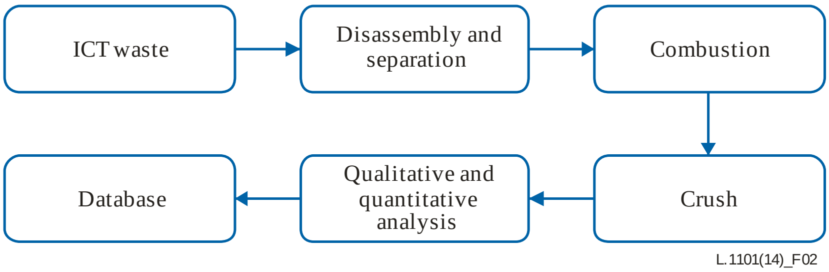


Figure 2 − Measurement process of rare metals in ICT goods

Figure 2 shows a rare metal measurement process for ICT goods.

1) Collection of ICT waste:

- Collect ICT wastes for recycling among ICT goods disused.

2) Disassembly of components and separation of materials:

- Disassemble the parts (e.g., case, screws, PCB boards, LCD (liquid crystal display) panel, wires, etc.)

  NOTE – For example, the case may be plastic and LCD panel is made of glass and liquid crystal.

- Separate the materials (i.e., metal, plastic, metal/plastic mixture, and plastic/glass fibre complex material).

3) Combustion:

- Plastic materials (metal/plastic mixture and plastic/glass fibre complex material) can be removed by a general "combustion" procedure, leaving only inorganic materials containing rare metals.

4) Crush of PCB boards:

- Mill the PCB boards into particles for sizing to below 0.25 mm;
- Dissolve the particles into nitric-acid and aqua regia solution;
- Mix the remaining material with other milled materials.

5) Elementary concentration analysis:

- Measure the weights of disassembled parts:
- Analyse homogenous solid metals by XRF;
- Analyse the sample alloy for non-homogeneous solid metals by ICP-MS.

6) Database:

- Record the quantities and qualities of rare metals in the form of, for example, [ITU-T L.1100].

6.2 Rare metal measurement methods for ICT goods

A common measurement method can facilitate recycling information exchanges between producers and recyclers. Referring to [IEC 62321], this Recommendation recommends XRF and ICP-MS to characterize rare metals for homogeneous and non-homogeneous composition materials. This is because both XRF and ICP-MS can support simultaneous measurement of quantity and quality in appropriate accuracy and ease of use. On the other hand, XRF is for homogeneous composition materials while ICP-MS is for non-homogeneous composition materials.

1) XRF measurement method for rare metals in ICT goods:

(1) Disassemble parts by weight (refer to items 2 and 5 in clause 6.1)

(2) Measure five points for each item three times

(3) Calculate the average value excluding the highest and the lowest value

(4) Record results in the form of, for example, [ITU-T L.1100], including the following information:

- Affiliation, address, location, experimenter
- Sample receipt date, test date
- Report identification (serial number and number of page)
- Experimental procedures and measurement equipment
- Detection limitation of all measurement equipment
- Test result (unit: wt%).

2) ICP-MS measurement method for rare metals in ICT goods:

(1) Disassemble parts by weight (refer to items 4) and 5) in clause 6.1)

(2) Measure five points for each item three times

(3) Calculate the average value excluding the highest and the lowest value

(4) Record results in the form of, for example, [ITU-T L.1100], including the following information:

- Affiliation, address, location, experimenter
- Sample receipt date, test date
- Report identification (serial number and number of page)
- Experimental procedures and measurement equipment
- Detection limitation of all measurement equipment
- Test result (unit: parts per million (ppm)).

6.3 Preparation of measurement samples

Disassembled parts of ICT wastes might have low contents of rare metals. All ICT wastes are roughly disassembled as modules, e.g., cases, screws, electric wires, and PCB boards. These roughly disassembled modules are then further disassembled into parts, which are weighed independently. The metal and non-metal elements of all parts are then separated.

1) Preparation of measurement samples and points for X-ray fluorescence (XRF) spectrometry

- More than five points should be measured for each measurement sample;
- Non-destructive measurement approach can apply to glasses, screws and cases;
- Destructive measurement approach applies to milled particles or to a cross section by cutting a non-homogeneous measurement sample. In the case of destructive sampling approach, the mass and weights of the test portion should be measured as required by the calibration method.

2) Preparation of measurement samples for ICP-MS

- More than five measurement samples should be measured.

In the case of ICT goods, the sample shall first be mechanically destroyed into the powder by the appropriate means (e.g., grinding, milling or mill-cutting) for chemical digestion of the powder. In order to ensure a representative sample is taken at this step, a certain particle size is required for digestion with aqua regia for preparation of a measurement sample). Wet digestion is recommended for the digestion of metals, with the exception of metals containing significant amounts of Si, Zr, Hf, Ti, Ta, Nb or W. The resulting concentrated solutions may be directly used in ICP-MS.

Appendix I

Case study for measurement of rare metals

(This appendix does not form an integral part of this Recommendation.)

A Korean experiment is reported as a case study of rare metals measurement. The following ICT goods were tested:

1) Smartphone: five sets

2) Laptop: five sets

The selected ICT goods (five sets of each good) were treated together and their average of rare metals quantity was calculated after measurement steps, because disassembled parts might have low contents of rare metals. All ICT goods were roughly disassembled into modules, e.g., cases, screws, electric wires, and PCB boards. The roughly disassembled modules were completely disassembled into parts, and then such parts were weighted independently and separated into metal and non-metal elements.

I.1 XRF measurement method

(1) The total content of the disassembled metal was weighted.

(2) The cases and screws were measured by X-ray fluorescence (XRF) to determine the rare metal content as well as concentration level of major metals.

(3) The metals in electric wires, metal-plastic composites, magnets and vibrators were measured by XRF to determine their rare metal content as well.

(4) The results of the five test samples were averaged.

I.2 ICP-MS measurement method

(1) PCB boards (motherboard, sub-board, power board, and general board) were burned in a furnace In order to remove organic plastics by a general combustion procedure and let inorganic metal elements remain. The weight of the residual inorganic metal elements was measured.

(2) The residual material from the PCB boards was milled to the particle sizes (average: 0.10 mm, maximum: 0.25 mm).

(3) The powdered PCB board sample was pre-treated for analysis by ICP-MS:

- Hydrofluoric (HF)＋HNO_3 dissolution: Ta, W, Nb, Sb
- Aqua regia (3HCl + HNO_3) solution treatment: Cu, Fe, Al, Pb, Au, Pd
- HCl (6 mol) dissolution of precipitates after aqua regia treatment: Ag.

(4) The remaining parts (i.e., other accessories) except PCB boards were also processed by combustion, milling, sampling, and ICP-MS measurement to analyse rare metal content (especially, noble metals such as Au, Ag and Pd). These parts can be combined with PCB boards in measurements situations.

(5) The results of the five test samples were averaged.

I.3 Examples result of measurement of rare metals in smartphone parts

The smartphone parts are disassembled as shown in Table I.1:

Table I.1 − Disassembled smartphone

Case	 
LCD	
Cable, antenna	
Vibrator	 
PCB board/ Noble-metal-containing parts	 

The general information of the smartphone for measurement is shown in Table I.2 according to [ITU-T L.1100].

Table I.2 – General information

a. Manufacturer	**A**
b. Model name	**Non-disclosure**
c. Model number	**Non-disclosure**
d. Certification authority	**KIRAM, Korea**
e. Certification number	**2012-0001**
f. Issue date	**1 November 2012**

The results of XRF analysis for quantities and qualities of major metals and rare metals are shown in Tables I.3 and I.4.

Table I.3 − XRF analysis results of major metals in smartphone parts (unit: wt%)

Metal species	Al	Fe	Ni	Cu	Zn	Sn	Pb	Br
Content	2.4	3.2	2.3	38	1.3	3	0.086	1.2

Table I.4 − XRF analysis results of rare metals in smartphone parts

Alkaline earth metal

Module and part name	Maker	Model number	Alkaline earth metal (ppm)				
			Li	Ca	Be	Sr	Ba
All modules	A	Non-disclosure	0	0	0	0	15000

Metalloid

Module and part name	Maker	Model number	Metalloid (ppm)			
			Ge	Bi	Se	Te
All modules	A	Non-disclosure	0	0	0	0

Iron group

Module and part Name	Maker	Model number	Metalloid (ppm)
			Co
All modules	A	Non-disclosure	0

Boron group

Module and part name	Maker	Model number	Boron group (ppm)			
			B	Ga	In	Tl
All modules	A	Non-disclosure	0	0	0	0

High fusion point metal

Module and part name	Maker	Model number	High fusion point metal (ppm)										
			Ti	Zr	Hf	V	Nb	Ta	Cr	Mo	W	Mn	Re
All modules	A	Non-disclosure	0	0	0	0	0	0	0	0	0	0	0

Platinum group

Module and part name	Maker	Model number	Platinum group (ppm)					
			Ru	Rh	Pd	Os	Ir	Pt
All modules	A	Non-disclosure	0	0	0	0	0	0

Rare earth

Module and part name	Maker	Model number	Rare earth (ppm)																
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
All modules	A	Non-disclosure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The results of ICP-MS analysis for quantities and qualities of major metals and rare metals are shown in Tables I.5 and I.6.

Table I.5 − ICP-MS analysis results of major metals in smartphone parts (unit: ppm)

Metal species	As	Cd	Sb	Ag	Au
Content	71	3	400	650	1200

Table I.6 − ICP-MS analysis results of rare metals in smartphone parts

Alkaline earth metal

Module and part name	Maker	Model number	Alkaline earth metal(ppm)				
			Li	Ca	Be	Sr	Ba
All modules	A	Non-disclosure	0	0	6	0	0

Metalloid

Module and part name	Maker	Model number	Metalloid (ppm)			
			Ge	Bi	Se	Te
All modules	A	Non-disclosure	20	1600	<1	0

Iron group

Module and part name	Maker	Model number	Metalloid (ppm)
			Co
All modules	A	Non-disclosure	210

Boron group

Module and part name	Maker	Model number	Boron group (ppm)			
			B	Ga	In	Tl
All modules	A	Non-disclosure	0	140	40	0

High fusion point metal

Module and part name	Make r	Model number	High fusion point metal (ppm)										
			Ti	Zr	Hf	V	Nb	Ta	Cr	Mo	W	Mn	Re
All modules	A	Non-disclosure	0	0	0	0	0	650	7000	200	4500	1000	0

Platinum group

Module and part name	Maker	Model number	Platinum group (ppm)					
			Ru	Rh	Pd	Os	Ir	Pt
All modules	A	Non-disclosure	11	<5	110	0	0	89

Rare earth

Module and part name	Maker	Model number	Rare earth (ppm)																
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
All modules	A	Non-disclosure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

I.4 Example result of measurements of rare metals in laptop parts

The laptop parts are disassembled as shown in Table I.7.

Table I.7 − Disassembled laptop

Case and screw	
LCD and case	
Keyboard and case	
Mainboard	
Hard disk and CD-ROM	

The general information of the laptop for measurement is shown in Table I.8 according to [ITU-T L.1100].

Table I.8 – General information

a. Manufacturer	**B**
b. Model name	**Non-disclosure**
c. Model number	**Non-disclosure**
d. Certification authority	**KIRAM, Korea**
e. Certification number	**2012-0002**
f. Issue date	**1 November 2012**

The results of XRF analysis results for quantities and qualities of major metals and rare metals are shown in Tables I.9 and I.10.

Table I.9 − XRF analysis results of major metals in laptop parts (unit: wt%)

Metal species	Al	Fe	Ni	Cu	Zn	Sn	Pb	Br
Content	2.6	4.7	0.84	21	1	2.2	1.1	3

Table I.10 − XRF analysis results of rare metals in laptop parts

Alkaline earth metal

Module and part name	Maker	Model number	Alkaline earth metal (ppm)				
			Li	Ca	Be	Sr	Ba
All modules	B	Non-disclosure	0	0	0	0	7000

Metalloid

Module and part name	Maker	Model number	Metalloid (ppm)			
			Ge	Bi	Se	Te
All modules	B	Non-disclosure	0	0	0	0

Iron group

Module and part name	Maker	Model number	Metalloid (ppm)
			Co
All modules	B	Non-disclosure	0

Boron group

Module and part name	Maker	Model number	Boron group (ppm)			
			B	Ga	In	Tl
All modules	B	Non-disclosure	0	0	0	0

High fusion point metal

Module and part name	Maker	Model number	High fusion point metal (ppm)										
			Ti	Zr	Hf	V	Nb	Ta	Cr	Mo	W	Mn	Re
All modules	B	Non-disclosure	0	0	0	0	0	0	0	0	0	0	0

Platinum group

Module and part name	Maker	Model number	Platinum group (ppm)					
			Ru	Rh	Pd	Os	Ir	Pt
All modules	B	Non-disclosure	0	0	0	0	0	0

Rare earth

Module and part name	Maker	Model number	Rare earth (ppm)																
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
All modules	B	Non-disclosure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The results of ICP-MS analysis results for quantities and qualities of major metals and rare metals are shown in Tables I.11 and I.12.

Table I.11 − ICP-MS analysis results of major metals in laptop parts (unit: ppm)

Metal species	As	Cd	Sb	Ag	Au
Content	17	2	2500	1100	940

Table I.12 − ICP-MS analysis results of rare metals in laptop parts

Alkaline earth metal

Module and part name	Maker	Model number	Alkaline earth metal (ppm)				
			Li	Ca	Be	Sr	Ba
All modules	B	Non-disclosure	0	30	55	0	0

Metalloid

Module and part name	Maker	Model number	Metalloid (ppm)			
			Ge	Bi	Se	Te
All modules	B	Non-disclosure	<10	100	<1	<1

Iron group

Module and part name	Maker	Model number	Metalloid (ppm)
			Co
All modules	B	Non-disclosure	120

Boron group

Module and Part name	Maker	Model number	Boron group (ppm)			
			B	Ga	In	Tl
All modules	B	Non-disclosure	0	10	<10	0

High fusion point metal

Module and part name	Maker	Model number	High fusion point metal(ppm)										
			Ti	**Zr**	**Hf**	**V**	**Nb**	**Ta**	**Cr**	**Mo**	**W**	**Mn**	**Re**
All modules	B	Non-disclosure	0	0	0	0	0	5800	1000	36	11	7700	0

Platinum group

Module and part name	Maker	Model number	Platinum group(ppm)					
			Ru	**Rh**	**Pd**	**Os**	**Ir**	**Pt**
All modules	B	Non-disclosure	19	<5	360	0	0	3

Rare earth

Module and part name	Maker	Model number	Rare earth(ppm)																
			La	**Ce**	**Pr**	**Nd**	**Pm**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Sc**	**Y**
All modules	B	Non-disclosure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bibliography

[b-ITU-T L.1400] Recommendation ITU-T L.1400 (2011), *Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies*.

[b-EAG] Evans Analytical Group, *Analytical Resolution versus Detection Limit*, http://www.eag.com/documents/analytical-resolution-versus-detection-limit-BR004.pdf

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