**ISO/DIS 22928-1:2023(E)**

Date: 2023-05-10

ISO/TC 298/WG 4

Secretariat: SAC

**Rare earth — Analysis by wavelength dispersive X-ray fluorescence spectrometry (WD-XRFS) — Part 1: Determination of composition of rare earth magnet scraps using standardless XRF commercial packages**

DIS stage

© ISO 2023

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO’s member body in the country of the requester.

ISO Copyright Office

CP 401 • CH-1214 Vernier, Geneva

Phone: + 41 22 749 01 11

Email: copyright@iso.org

Website: [www.iso.org](https://www.iso.org/)

Published in Switzerland.

Contents

[Foreword iv](#_Toc134627077)

[Introduction v](#_Toc134627078)

[1 Scope 1](#_Toc134627079)

[2 Normative references 2](#_Toc134627082)

[3 Terms and definitions 2](#_Toc134627083)

[4 Handling recyclable magnet resources 3](#_Toc134627084)

[4.1 Dismantling EOL scrap 3](#_Toc134627085)

[4.1.1 General 3](#_Toc134627086)

[4.1.2 Dismantling components containing rare earth magnets 3](#_Toc134627087)

[4.2 Demagnetization 3](#_Toc134627088)

[4.2.1 General 3](#_Toc134627089)

[4.2.2 Heat treatment 4](#_Toc134627090)

[4.2.3 Alternating magnetic fields 4](#_Toc134627091)

[4.3 Cleaning magnet scrap 4](#_Toc134627092)

[5 X-ray fluorescence analysis 4](#_Toc134627093)

[5.1 General 4](#_Toc134627094)

[5.2 Sample preparation 4](#_Toc134627095)

[5.2.1 General 4](#_Toc134627096)

[5.2.2 Bulk samples 5](#_Toc134627097)

[5.2.3 Powder samples 5](#_Toc134627098)

[5.3 Use of commercial XRF standardless packages for analysis 5](#_Toc134627099)

[5.4 Instrument setup 5](#_Toc134627100)

[5.4.1 General 5](#_Toc134627101)

[5.4.2 Measurement conditions 6](#_Toc134627102)

[5.5 Expression of results 6](#_Toc134627104)

[5.5.1 General comments 6](#_Toc134627105)

[5.5.2 Reporting of results 6](#_Toc134627106)

[Annex A (informative) Interlaboratory test results 8](#_Toc134627107)

[Bibliography 10](#_Toc134627112)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](https://www.iso.org/directives-and-policies.html)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO’s adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](https://www.iso.org/foreword-supplementary-information.html).

This document was prepared by Technical Committee ISO/TC 298, *Rare earth*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](https://www.iso.org/members.html).

Introduction

Rare earth element (REE) magnets, especially neodymium-based magnets, can be found in numerous different applications.[4] According to some rough estimates, the annual demand of REE magnets was nearly 78 kilotons in 2015.[5] Based on those estimates, six major applications (namely wind turbines, hard disk drives, electric vehicles, e-bikes, audio speakers and air conditioners) account for nearly 60 % of the total demand. As components utilizing REE magnets continue to accumulate, the REE repository created by human activity will be crucial to address in the future by recycling.

The commercially used REE magnets can be divided into two main categories: samarium-cobalt (Sm-Co)-based magnets and neodymium-iron-boron (Nd-Fe-B)-based magnets:

— In Sm-Co-based REE magnets, SmCo5 and Sm2Co17 are the two technically important compositions. In the Sm2Co17 magnet, the concentration of Co is sometimes partially replaced by other transition metal elements.

— .A

The mass of REE magnet present in each product varies greatly. Additionally, the concentration of different REE elements within the magnet itself can vary greatly. For example, the incorporation of Dy into Nd-Fe-B magnets can be in the range of < (1 to 10) % mass fraction. These factors contribute towards challenges in the recycling efficiency of REE magnets.

In the case of magnets derived from end-of-life (EOL) equipment, dismantling is carried out. Apart from REE magnets found inside wind turbines and electronic vehicles, the physical extraction of REE magnets from electronic application scrap is very challenging due to the complexity and small size of the components. This type of scrap is usually shredded. The shredded scrap is then sorted into ferrous and non-ferrous scrap. During the shredding process, the recovery rates of REEs can drop by 90 %.[5] Appropriate guidelines for dismantling the EOL scrap is important for improving the REE recovery. Overall, effective recycling of REE requires information regarding the amount and nature of the REEs present in the magnet scrap.

This document specifies the measurement protocol for assessing the composition of REE magnet scrap. Procedures for dismantling components containing scrap and for cleaning and demagnetizing the scrap are provided. Guidelines for determining the composition of REE magnet scrap using standardless wavelength dispersive X-ray fluorescence (WD-XRF) commercial packages are specified.

This document

— (see Clause 4);

— (see Clause 5).

Rare earth — Analysis by wavelength dispersive X-ray fluorescence spectrometry (WD-XRFS) — Part 1: Determination of composition of rare earth magnet scraps using standardless XRF commercial packages

**can**

# Scope

This document specifies a protocol for the application of semi-quantitative standardless wavelength dispersive X-ray fluorescence (WD-XRFS) commercial packages for the assessment of the concentration of rare earth elements (REEs) contained in magnet scrap from end-of-life (EOL) products intended for recycling.

The concentration ranges of samples that may be appropriately analysed by this method are given in Tables 1 and 2, for each type of magnet scrap included in this document.

Table 1 — Concentration range of application for Nd-Fe-B magnet scrap major elements

|  |  |
| --- | --- |
| **Major elements** | **Range of concentration** % mass fraction |
| Fe | 1 to 70,0 |
| Nd | 1 to 40,0 |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

Table 2 — Concentration range of application for Nd-Fe-B magnet scrap minor elements

|  |  |
| --- | --- |
| **Minor elements** | **Range of concentration** % mass fraction |
| Pr | 1 to 10,0 |
| Dy | 1 to 10,0 |
| Tb | 1 to 10,0 |
| Gd | 1 to 10,0 |
| Ce | 1 to 10,0 |
| Ho | 1 to 10,0 |
| Ga | 1 to 10,0 |
| Co | 1 to 10,0 |
| Ni | 1 to 10,0 |
| Cu | 1 to 10,0 |
| Nb | 1 to 10,0 |
| Al | 1 to 10,0 |
| Zn | 1 to 10,0 |

NOTE Standardless XRF analysis will be carried out on all the elements between Na and U. The final report will contain the elements in scope that are over 1 % mass fraction.

# Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 22444-2, Rare earth — Vocabulary — Part 2: Metals and their alloys

ISO 22450, *Recycling of rare earth elements — Requirements for providing information on industrial waste and end-of-life products*

ISO/TS 22451, Recycling of rare earth elements — Methods for the measurement of rare earth elements *in industrial waste and end of life products*

# Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22444-2, ISO 22450, ISO/TS 22451 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at [https://www.iso.org/obp](https://www.iso.org/obp/ui)

— IEC Electropedia: available at <https://www.electropedia.org/>

3.1

neodymium-iron-boron magnet

Nd-Fe-B magnet

group of permanent magnets based on the Nd2Fe14B compound

Note 1 to entry: The composition of Nd-Fe-B magnets can vary greatly due to the addition of elements such as Dy or Tb to improve high-temperature properties.

3.3

sintered magnet

type of permanent magnet made by consolidation and thermal treatment to create a dense compact

Note 1 to entry: Sintered magnets have high anisotropy and maximum magnetism of above 30 MGOe.

Note 2 to entry: Sintered magnets are highly brittle and pyrophoric.

3.4

bonded magnet

type of magnet synthesized by mixing magnetic powder and binder material such as rubber or plastic to create a dense compact

Note 1 to entry: Bonded magnets usually have higher shape complexity and maximum magnetism of below 10 MGOe.

Note 2 to entry: Bonded magnets are prepared using moulding or compression without the use of thermal treatment.

3.5

recycler

organization with the facility to carry out *recycling* (3.6)

3.6

recycling

operation by which discarded products are reprocessed into products, product parts, materials or substances whether for the original or other purposes

[SOURCE: IEC/TR 62635:2012, 3.16]

3.7

end-of-life scrap

EOL scrap

scrap comprising recyclable materials provided by a collection facility of EOL products

# Handling recyclable magnet resources

## Dismantling EOL scrap

### General

REE magnets derived from the EOL scrap are often installed inside complex components and products. It is necessary to dismantle these EOL products to recover the incorporated magnets to reuse or recycle them. Reuse and recycling, important pillars for closing the loop in a circular product economy, require appropriate product information to allow identification, quantification and recovery of REE elements from magnets.

### Dismantling components containing rare earth magnets

The handler of the recyclable resources, as defined in ISO 22453, should provide the identification of parts that contain magnets for reuse or recycling that are not obviously readily identifiable and for which dismantling is recommended.

The following information should be provided:

a) manufacturer identification and contact details;

b) website;

c) country of origin;

d) identification of the magnet type;

e) location, size and/or mass;

f) sketches, drawings or pictures of the product containing the magnet;

g) recommended dismantling procedure, e.g. dismantling steps, tools to be used.

## Demagnetization

### General

REE magnets and scraps are generally magnetized. To measure the nature and content of REEs in these magnets, the first necessary step is to ensure their demagnetization.

In order to demagnetize the magnets, the magnetically aligned regions of the magnet, which are referred to as “magnetic domains”, shall be randomized to achieve a net zero magnetization state. This process can be achieved in a variety of ways. Two of the recommended ways are given in 4.2.2 and 4.2.3.

### Heat treatment

A magnet may be thermally demagnetized by heating it above its magnetic transition temperature, or Curie temperature, and cooling it in the presence of a zero magnetic field.

The Curie temperature greatly varies with the type of magnet.

EXAMPLE Nd-Fe-B magnets lose their magnetism beyond a temperature of 400 °C.

### Alternating magnetic fields

Another common way of demagnetizing is by subjecting the magnet to a series of alternating applied magnetic fields. This method decreases the remanence of the magnet by randomizing the alignment of the magnetic domains.

## Cleaning magnet scrap

Recovered magnets and magnet scrap shall be cleaned prior to analysis. The magnets are usually attached to a housing component with adhesives. In addition, magnets can also have a protective coating, often comprising a nickel-copper alloy, which should be removed when analysing a bulk sample.

A procedure is provided as follows:

a) The scrap should be initially cleaned with acetone to remove organic impurities, dust and other contaminants.

b) If adhesives are present, the scrap shall be fully immersed and sonicated inside an alkaline cleaning agent. The pH of the cleaning agent can be varied depending upon the nature and quantity of contaminants.

c) The Ni-Cu coatings of Nd-Fe-B magnets may be removed by immersing them in a 1 % volume bromine solution in ethanol for 60 min. This process should be carried out inside a chemical fume hood with all the necessary safety precautions.

# X-ray fluorescence analysis

## General

XRFS is a non-destructive technique used to determine the chemical composition of materials. In this technique, an analyte is irradiated with X-rays, resulting in the emission of characteristic fluorescent X-rays that correspond to the elementals within the analyte.

## Sample preparation

### General

Sample preparation should be conducted according to the sources (categories and condition) of the magnet scrap:

a) in cases where the magnet scrap is very homogeneous (e.g. coming from one type of product such as wind turbines or magnetic resonance imaging (MRI) equipment), the method for bulk sample preparation, as described in 5.2.2, should be conducted;

b) in cases where the magnetic scrap is inhomogeneous (e.g. coming from a mixture of different EOL products such as hard disk drives, automobiles, home appliances or industrial motors), the method described in 5.2.3 should be conducted.

### Bulk samples

#### Surface preparation

The surface of bulk solid samples shall be flat to ensure accurate analysis using XRF. Grinding the sample surface using a medium with grit size of 600 should be sufficient. Afterwards, the surface should be cleaned using an appropriate solvent in order to remove any grinding media or foreign substance.

#### Sample storage

It is good practice to prepare the surface of a sample immediately prior to analysis. However, if the sample cannot be analysed immediately, it should be stored in a vacuum desiccator or in an inert atmosphere glove box.

### Powder samples

#### Binder wax

Briquettes or tablets from powder to be analysed may be prepared using any commercially available wax.

#### Powder particle size

The powder should be pulverized if necessary. To minimize the particle size effect, powder with a size of less than 50 µm should be used. The powder size shall always be under 100 µm.

#### Weighing and mixing

A binder to powder ratio of 1:4 by mass should be used for the preparation of briquettes or tablets. Thoroughly mix the components in a container. Mixing during pulverization can also be used.

#### Pressing

The briquette or tablet should be pressed to a minimum of approximately 250 MPa (20 tonnes). The pressing can be done using collapsible aluminium cups or rings, or without these devices.

#### Sample storage

The sample should be stored in a vacuum desiccator.

## Use of commercial XRF standardless packages for analysis

Commercial standardless XRF packages which can calculate the composition while taking specific line overlaps into consideration should be used.

Commercial standardless XRF package software that is provided in most modern X-ray spectrometers to perform the elemental analysis of the magnet scrap should be used.

Such packages shall be used, provided that the following qualifications are met:

— all the signals to be used in the quantification of the elements of interest should be calibrated beforehand;

— the software is able to calculate instrument and element sensitivities from the database;

— the software is able to make drift corrections.

## Instrument setup

### General

For correct operation of the instrument and software, refer to the manufacturer’s recommendations.

### Measurement conditions

The analytical lines to be used for analysis and suggested conditions of measurement of specific elements are given in Table 2. The expected elements inside the sample to be measured shall be provided to the software.

Table 2 — Suggested analytical lines and operating conditions for wavelength
dispersive XRF (WDXRF) spectrometers

|  |  |
| --- | --- |
| **Element** | **Lines** |
| Pr | L*β* |
| Nd | L*α* |
| Gd | L*α* |
| Tb | L*α* |
| Dy | L*β* |
| Ce | L*β* |
| Ho | L*β* |
| Ga | L*α* |
| Fe | K*α* |
| Co | K*α* |
| Ni | K*α* |
| Nb | K*α* |
| Zr | K*α* |
| Cu | K*α* |
| Ti | K*α* |
| Al | K*α* |
| Zn | K*α* |

NOTE 1 Voltages are variable depending upon the characteristics of the X-ray tube and generator that are used. The values suggested in Table 2 are compatible with most of the XRFS systems currently available in the market today.

NOTE 2 All devices are described as generic.

NOTE 3 All operating conditions assume a voltage ranging from 50 kV to 60 kV, a LiF200/LiF220 crystal, a medium to fine collimator and a gas proportional/scintillator detector.

## Expression of results

### General comments

The conversion of intensities to concentrations can be done with most of the commercial software packages accompanying the XRF instruments.

### Reporting of results

**5.5.2.1** The result form shall be generated in accordance with ISO 22450.

**5.5.2.2** The concentrations shall be reported as mass percentages of each element.

**5.5.2.3** The detected concentrations shall be normalized to 100 % mass fraction.

**5.5.2.4** The normalized concentration shall incorporate 1 % mass fraction of boron.

**5.5.2.5** The type of magnet (sintered magnet or bonded magnet) shall be reported along with the results. For bonded magnets, the appropriate amount of binder content shall be incorporated in the normalized concentration.

**5.5.2.6** The concentrations will be reported as ranges.

EXAMPLE (1 to 5) % mass fraction, (5 to 10) % mass fraction, (10 to 15) % mass fraction, (15 to 20) % mass fraction, > 20 % mass fraction.

NOTE Additional details can be provided upon agreement between the concerned parties.

**5.5.2.7** Elements with a concentration under 1 % mass fraction shall be omitted from the report.

**5.5.2.8** Additional information can be provided in accordance with the specific requirement.

1. (informative)

Interlaboratory test results
	1. Precision — Calculation of *r*, *Rw* and *R*

The precision calculations of the data are summarized in Tables A.1 to A.3. For some of the levels, negative value of variance was estimated due random effects. In accordance with ISO 5725-2:2019 these values are assumed to be zero. As a result, the value of *r* is equal to *R*w for those levels.

Table A.1 — *r*, *R*w and *R* values for sample NdFeB-1

| **Levels** | **Level 1-1** | **Level 1-2** | **Level 1-3** | **Level 1-4** | **Level 1-5** |
| --- | --- | --- | --- | --- | --- |
| **Sample** | **NdFeB 1 (sintered)** |
| **Element** | **Fe** | **Nd** | **Pr** | **Tb** | **Dy** |
| Number of data | 6 | 5 | 6 | 5 | 4 |
| Mean | % | 67,40 | 21,98 | 5,17 | 1,59 | 1,08 |
| *sr* | % | 0,0060 | 0,0044 | 0,0008 | 0,0025 | 0,0012 |
| *sRw* | % | 0,0094 | 0,0315 | 0,0055 | 0,0025 | 0,0012 |
| *sR* | % | 0,5559 | 0,3927 | 0,1078 | 0,0115 | 0,0230 |
| *r* | % | 0,0168 | 0,0123 | 0,0024 | 0,0070 | 0,0035 |
| *R*w | % | 0,0263 | 0,0878 | 0,0055 | 0,0070 | 0,0035 |
| *R* | % | 1,5554 | 1,0988 | 0,3015 | 0,0363 | 0,0643 |
| *CV,r* | % | 2,31 | 4,99 | 5,83 | 2,87 | 5,94 |
| **Key***sr*  repeatability, *sRw*  intralaboratory reproducibility, *sR* reproducibility, *r*  repeatability limit, *R*w intralaboratory reproducibility limit, *R*  reproducibility limit, *CV,r*  coefficient of variation, reproducibility |

Table A.2 — *r, Rw* and *R* values for sample NdFeB-2

| **Level** | **Level 2-1** | **Level 2-2** | **Level 2-3** | **Level 2-4** | **Level 2-5** |
| --- | --- | --- | --- | --- | --- |
| **Sample** | **NdFeB 2 (sintered)** |
| **Element** | **Fe** | **Nd** | **Pr** | **Tb** | **Dy** |
| Number of data | 6 | 6 | 5 | 5 | 4 |
| Mean | % | 66,03 | 23,38 | 5,67 | 0,33 | 1,30 |
| *sr* | % | 0,0609 | 0,0747 | 0,0282 | 0,0019 | 0,0002 |
| *sRw* | % | 0,0609 | 0,0747 | 0,0282 | 0,0019 | 0,0002 |
| *sR* | % | 0,0908 | 0,3301 | 0,1879 | 0,0096 | 0,0426 |
| *r* | % | 0,1704 | 0,2090 | 0,0790 | 0,0053 | 0,0006 |
| *R*w | % | 0,1704 | 0,2090 | 0,0790 | 0,0053 | 0,0052 |
| *R* | % | 0,3681 | 1,0424 | 0,0061 | 0,0274 | 0,1194 |
| *CV,r* | % | 0,56 | 4,46 | 6,28 | 8,23 | 9,16 |
| **Key***sr*  repeatability, *sRw*  intralaboratory reproducibility, *sR* reproducibility, *r*  repeatability limit, *R*w intralaboratory reproducibility limit, *R*  reproducibility limit, *CV,r*  coefficient of variation, reproducibility |

Table A.3 — *r, Rw* and *R* values for sample NdFeB-3

| **Level** | **Level 3-1** | **Level 3-2** | **Level 3-3** |
| --- | --- | --- | --- |
| **Sample** | **NdFeB 3 (Bonded)** |
| **Element** | **Fe** | **Nd** | **Pr** |
| Number of data | 6 | 6 | 6 |
| Mean | % | 68,60 | 28,98 | 0,18 |
| *sr* | % | 0,0161 | 0,0151 | 0,0002 |
| *sRw* | % | 0,0161 | 0,0151 | 0,0004 |
| *sR* | % | 0,8522 | 0,4737 | 0,0012 |
| *r* | % | 0,0450 | 0,0423 | 0,0004 |
| *R*w | % | 0,0450 | 0,0423 | 0,0012 |
| *R* | % | 2,4059 | 1,3421 | 0,0035 |
| *CV,r* | % | 3,51 | 4,63 | 0,66 |
| **Key***sr*  repeatability, *sRw*  intralaboratory reproducibility, *sR* reproducibility, *r*  repeatability limit, *R*w intralaboratory reproducibility limit, *R*  reproducibility limit, *CV,r*  coefficient of variation, reproducibility |

Bibliography

[1] ISO 5725-2:2019, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

[2] ,

[3] IEC/TR 62635:2012, Guidelines for end-of-life information provided by manufacturers and recyclers and for recyclability rate calculation of electrical and electronic equipment

[4] Yang, Y., Walton, A, Sheridan, R., Guth, K., Gauß, R., Gutfleisch, O., Buchert, M., Steenari, B-M, Van Gerven, T., Jones, P.T., Binneman,s K. REE Recovery from End-of-Life NdFeB Permanent Magnet Scrap: A Critical Review. *J. Sustain. Metall*. 2017, 3, 122–149

[5] Benjamin, S., Yanping, X., Allan, W., John, S., Rex, H., Rene, K., Geert, V, Gert, J.K. Life Cycle Inventory of the Production of Rare Earths and the Subsequent Production of NdFeB Rare Earth Permanent Magnets. *Environmental Science & Technology*. 2014, 48(7), 3951–3958