INTERNATIONAL STANDARD

ISO 22444-1

First edition
2020-10

Rare earth — Vocabulary —

Part 1: Minerals, oxides and other compounds

Terres rares — Vocabulaire —

Partie 1: Minéraux, oxydes et autres composants

Reference number
ISO 22444-1:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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.

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

A list of all parts in the ISO 22444 series can be found on the ISO website.

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.

Introduction

Rare earth elements are widely used. Different business and industry sectors have various descriptions for rare earth elements and their compounds and alloys. Therefore, it is of vital importance to unify the terminology used in the rare earth industry.

About 250 minerals contain significant amounts of rare earth elements although there are only a few that are economically exploited at this time. Various rare earth oxides and other compounds are obtained from these rare earth minerals as they are processed through to intermediate products and on to final products.

This document specifies terms for use by producers, consumers and traders in the field of rare earth minerals, oxides and other compounds. This document will serve as a reference that will help to reduce discrepancies or trade disputes caused by inconsistencies in terms used when dealing with rare earth minerals, oxides and other compounds.

Rare earth — Vocabulary —

Part 1: **Minerals, oxides and other compounds**

1 Scope

The document defines the terms for rare earth minerals, oxides and other compounds, as well as for related production processes.

This document can be used as a reference to unify technical terms in rare earth production, application, inspection, circulation, trading, scientific research and education.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
rare earth element
collective name for scandium (Sc), yttrium (Y) and the lanthanides (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu), which was approved by the International Union for Pure and Applied Chemistry (IUPAC) in its 2005 Nomenclature of Inorganic Chemistry Recommendations[1]

Note 1 to entry: Certain terms and corresponding abbreviated terms are common such as rare earth element (REE or RE) and *rare earth oxide (REO)* (5.2.1).

Note 2 to entry: Rare earth elements are frequently referred to as being either light rare earth (LREE), medium rare earth (MREE) or heavy rare earth (HREE), with LREE including the elements between lanthanum (La) and neodymium (Nd), MREE including the elements between samarium (Sm) and gadolinium (Gd), and HREE including the elements from terbium (Tb) to lutetium (Lu) as well as scandium (Sc) and yttrium (Y).

Note 3 to entry: Didymium is commonly used to express a mixture of the elements Pr and Nd.

Note 4 to entry: Characteristics of rare earth elements are described in Annex A.

3.2
rare earth mineral
mineral containing one or more *rare earth elements* (3.1)

Note 1 to entry: Rare earths can be present as a simple compound, incorporated in the lattice of another mineral, or sorbed to another mineral, such as *bastnaesite* (4.1.1), *monazite* (4.1.2) or montmorillonite as in ionic clay deposits.

3.3
rare earth ore
rare earth mineralization found in nature in various types of ore deposit

Note 1 to entry: Those deposit types that are now, or have previously been, commercially exploited include *Baiyun Obo ore* (4.2.1), *ion-adsorption rare earth ore* (4.2.2), *carbonatite/alkalic pipe* (4.2.3), *weathered carbonatite* (4.2.4) and *beach sand* (4.2.5).

3.4
rare earth deposit
area or volume of the earth's crust where there is an accumulation of *rare earth minerals* (3.2), with or without other valuable minerals, that is of economic interest

3.5
rare earth grade
mass fraction of *rare earth oxide (REO)* (5.2.1) in the deposit/concentrate or tailings

Note 1 to entry: The grade can be present as a percentage or as either kg/t or g/t. Statements of grade shall clearly state if the data are given on a REE, RE or REO basis.

Note 2 to entry: When a rare earth metal mass is converted to oxide mass, all *rare earth elements (REEs)* (3.1) should be taken as trivalent except for the following oxide forms: ceric oxide, CeO_2, praseodymium oxide, Pr_6O_{11}, and terbium oxide, Tb_4O_7.

3.6
rare earth mineral resource and mineral reserve
resources of ore or minerals containing rare earths, which can be mined legally and profitably under existing conditions

Note 1 to entry: Indicated reserve is the estimate of ore computed from boreholes, outcrops and developmental data, and is projected for a reasonable distance on geologic evidence.

3.7
rare earth content
total rare earth content
mass fraction of rare earths in the material

Note 1 to entry: For *rare earth oxides* (5.2.1) and other compounds, the fraction is generally provided as a percentage of rare earth oxide, i.e. % REO or % TREO. For metals and alloys, the content is generally provided as a percentage of rare earth metal, i.e. % REM or % TREM.

3.8
rare earth distribution
mass fraction of each individual rare earth in a material containing a mixture of rare earths compared to the *rare earth content* (3.7) of the material

Note 1 to entry: The distribution is normally expressed as the percentage of rare earth metal, i.e. % RE or % REM for metals and alloys, and percentage of *rare earth oxide* (5.2.1), i.e. % REO, for compounds and other materials.

3.9
average molar mass of mixed rare earth compounds
$\bar{M}$
ratio of the total mass of all rare earth compounds to their total number of moles, as shown by the formula:

$$\bar{M} = \frac{m_{\text{total}}}{n_{\text{total}}} = \frac{\sum_{i=1}^{N} m_i}{\sum_{i=1}^{N} \frac{m_i}{M_i}} = \frac{m_1 + m_2 + \ldots + m_N}{\frac{m_1}{M_1} + \frac{m_2}{M_2} + \ldots + \frac{m_N}{M_N}}$$

where

m_{total} is the total mass of mixed rare earths, in g;

n_{total} is the total number of moles of mixed rare earths, in moles;

m_i is the mass of rare earth compound *i*, *i* = 1, 2, ..., *N*, in g;

M_i is the molar mass of rare earth compound *i*, *i* = 1, 2, ..., *N*. The basic unit of calculation is $1/x(RE_xB_y)$, in g/mol.

Note 1 to entry: $\bar{M}$ is given in g/mol.

EXAMPLE 1 The average molar mass of a mixed *rare earth oxide* (5.2.1) containing 40 % mass of lanthanum oxide and 60 % of yttrium oxide is calculated as follows:

m_{La2O3} = 40 units, m_{Y2O3} = 60 units, M_{La} = 325,81/2 = 162,90 g/mol, M_Y = 225,81/2 = 112,90 g/mol

$$\bar{M}=\frac{40+60}{\frac{40}{162,9}+\frac{60}{112,9}}=128,7\ \text{g/mol}$$

EXAMPLE 2 The average molar mass of a mixed *rare earth oxide* (5.2.1) containing 25 % of praseodymium oxide and 75 % of neodymium oxide is calculated as follows:

m_{Pr6O11} = 25 units, m_{Nd2O3} = 75 units, M_{Pr} = 1 021,44/6 = 170,24 g/mol, M_{Nd} = 336,48/2 = 168,24 g/mol

$$\bar{M}=\frac{25+75}{\frac{25}{170,2}+\frac{75}{168,2}}=168,7\ \text{g/mol}$$

EXAMPLE 3 The average molar mass of a mixed *rare earth chloride* (5.2.2) containing 40 % of lanthanum chloride and 60 % of cerium chloride is calculated as follows:

m_{LaCl3} = 40 units, m_{CeCl3} = 60 units, M_{LaCl3} = 245,26 g/mol, M_{CeCl3} = 246,48 g/mol

$$\bar{M}=\frac{40+60}{\frac{40}{245,26}+\frac{60}{246,48}}=246,0\ \text{g/mol}$$

3.10
rare earth impurity
undesirable *rare earth element* (3.1), apart from the target rare earth component(s) in a rare earth product

3.11
non-rare earth impurity
undesirable non-rare earth component in a rare earth product

EXAMPLE Fe, Al, Ca, SO_4^{2-}.

3.12
rare earth purity
absolute rare earth purity
mass fraction of a specified *rare earth element* (3.1) or *rare earth oxide* (5.2.1) in a rare earth product

Note 1 to entry: It is expressed as a percentage and with the basis (REM or REO) stated.

Note 2 to entry: The content of target element in the oxide, metal or compound is expressed by purity when the content is higher than 90 %.

3.13
relative rare earth purity
mass fraction of the specified *rare earth element* (3.1) or *rare earth oxide* (5.2.1) out of the *rare earth content* (3.7)

Note 1 to entry: It is expressed as a percentage and with the basis (REM or REO) stated.

4 Terms related to rare earth minerals and ore

4.1 Rare earth minerals

4.1.1
bastnaesite
yellow, reddish brown, light green or brown carbonate-fluoride mineral, usually containing 65 % to 75 % *rare earth oxide* (5.2.1), with the formula of (Ce,La,Nd,Pr) CO_3F

Note 1 to entry: The family of carbonate-fluoride minerals includes bastnaesite-(Ce) with a formula of (Ce,La) CO_3F, bastnaesite-(La) with a formula of (La,Ce)CO_3F, and bastnaesite-(Y) with a formula of (Y,Ce)CO_3F. Most of the mineral is bastnaesite-(Ce), and cerium is by far the most common of the rare earths in this class of minerals.

Note 2 to entry: The Mohs hardness of the mineral is 4 to 4,5, and the density is generally 4 700 kg/m^3 to 5 100 kg/m^3.

Note 3 to entry: The mineral is soluble in HCl, H_2SO_4, HNO_3 and H_3PO_4.

4.1.2
monazite
yellow-brown, brown, red and sometimes green mineral, usually containing 55 % to 70 % of *rare earth oxide* (5.2.1), with the formula of (Ce,La,Nd,Pr,Th)PO_4

Note 1 to entry: The mineral is usually found in small free crystals, and the mineral composition is mostly light rare earth. The presence of thorium can create radioactivity issues.

Note 2 to entry: The Mohs hardness of the mineral is 5,05 to 5,5, and the density is generally 4 900 kg/m^3 to 5 500 kg/m^3.

Note 3 to entry: The mineral is soluble in H_3PO_4, H_2SO_4 and $HClO_4$ depending on composition and pre-treatment processes.

4.1.3
xenotime
yellow, brown and sometimes yellowish green *rare earth phosphate* (5.2.9) mineral, typically containing 50 % to 65 % *rare earth oxide* (5.2.1), which is generally yttrium phosphate (YPO_4)

Note 1 to entry: Besides yttrium, the mineral often contains other heavy *rare earth elements* (3.1) such as dysprosium, erbium, terbium and ytterbium. The presence of thorium can create radioactivity issues. The mineral is a significant source of yttrium and heavy rare earth metals.

Note 2 to entry: The Mohs hardness of the mineral is 4 to 5 and the density is generally 4 400 kg/m^3 to 5 100 kg/m^3.

4.1.4
fergusonite
typically yellow, tawny or black complex mineral, typically containing 43 % to 53 % *rare earth oxide* (5.2.1), with the chemical formula of (Y,REE) NbO_4

Note 1 to entry: Usually, the main rare earth in the mineral is yttrium, but sometimes cerium, lanthanum and neodymium can be substituted.

Note 2 to entry: The Mohs hardness of the mineral is 5,5 to 6,5 and the density is generally 4 900 kg/m^3 to 5 800 kg/m^3.

Note 3 to entry: The mineral is partially dissolved in HCl and dissolved in H_2SO_4, H_3PO_4 and HF depending on composition and pre-treatment processes.

4.1.5
loparite
black, ash black or streak reddish brown mineral, typically containing 30 % to 40 % *rare earth oxide* (5.2.1), with a general chemical formula of $(Na,Ce,Ca,La,Sr)O_3(Ti,Nb)$

Note 1 to entry: The Mohs hardness is 5,6 to 6,0 and the density is generally 4 600 kg/m^3 to 4 900 kg/m^3.

Note 2 to entry: If the Nb_2O_3 is greater than 25 %, it is called niobium-rich loparite.

Note 3 to entry: The mineral is generally not soluble in acids except for hydrofluoric acid.

4.2 Rare earth ores and concentrate

4.2.1
Baiyun Obo ore
mixed *rare earth ore* (3.3) containing *rare earth elements* (3.1) in *bastnaesite* (4.1.1) and *monazite* (4.1.2) and iron as magnetite and hematite

Note 1 to entry: It is named after Baiyun Obo in Inner Mongolia where the ore is processed for the production of *rare earth concentrate* (4.2.6) and iron concentrates.

4.2.2
ion-adsorption rare earth ore
clay minerals, such as montmorillonite, that have sorbed rare earth ions released by intense weathering of primary *rare earth minerals* (3.2) through ion exchange mechanisms, also known as weathered crust elution-deposited *rare earth ore* (3.3)

Note 1 to entry: The ore is a major source of heavy rare earths and is found in various parts of the world, generally in the tropics.

4.2.3
carbonatite/alkalic pipe
rare earth deposits (3.4) hosted by carbonatite/alkalic pipes and overlying alkali volcanic deposits

Note 1 to entry: The rare earth mineralization is often in the form of *bastnaesite* (4.1.1) although *monazite* (4.1.2) is also frequently encountered. Gangue minerals are usually carbonates.

EXAMPLE Mountain Pass in the USA, Kvanefjeld in Greenland.

4.2.4
weathered carbonatite
carbonatites having experienced intensive weathering and leaching processes that have, in many cases, led to enrichment of the rare earths

EXAMPLE Mt. Weld deposit in Australia, the Tomtor deposit in Russia.

4.2.5
beach sand
rare earth minerals (3.2) that generally have high specific gravities and can be concentrated by the action of flowing water in coastal or riverine heavy mineral deposits

Note 1 to entry: Such deposits are common in Australia, India and Southern Africa.

4.2.6
rare earth concentrate
material enriched in rare earths, obtained by physical or chemical processes and in the form of a solid or solution, and suitable as the feed to a hydrometallurgical or separation plant

Note 1 to entry: Purified mixed rare earth concentrate is the concentrate that is obtained by chemical processes, containing very few impurities, in the form of a solid or solution that is produced from the leach solution obtained from *ion-adsorption rare earth ore* (4.2.2) or mixed mineral concentrate, and suitable as the feed to a separation plant. It has a similar *rare earth distribution* (3.8) to the rare earth concentrate.

EXAMPLE Mineral concentrate of *monazite* (4.1.2), mixed mineral concentrate of *bastnaesite* (4.1.1) and monazite, mixed *rare earth carbonate* (5.2.3), *rare earth oxide* (5.2.1) or *rare earth chloride* (5.2.2) solution prepared from leach solution of ion-adsorption rare earth ore.

5 Terms related to rare earth oxides and other compounds

5.1 General terms

5.1.1
individual rare earth compound
compound dominantly containing only one *rare earth element* (3.1)

5.1.2
mixed rare earth compound
compound dominantly containing two or more *rare earth elements* (3.1) and obtained by processing a mixed rare earth material to partially separate certain groups of rare earths

Note 1 to entry: Didymium compounds are compounds containing a mixture of the elements praseodymium (Pr) and neodymium (Nd), in which Pr is generally more than 18 %.

5.1.3
rare earth-bearing compound
compound made from *rare earth element(s)* (3.1) and another constituent element with significantly different physical or chemical properties that, when combined, produce a compound with characteristics different from the individual component

Note 1 to entry: The compound has the characteristics of optics, mechanics, electricity, catalysis, abrasion, thermalelectricity, etc.

EXAMPLE Complex oxide of cerium zirconium, yttria-stabilized zirconia (YSZ), (Sr,Ca)$AlSiN_3$: Eu^{2+} nitride red powder ($RE_xAl_yO_z$), lanthanum chromite ($LaCrO_3$).

5.1.4
separated rare earth product
compound containing one or more rare earths that have been substantially separated from other rare earths

EXAMPLE Praseodymium and neodymium oxide/didymium oxide, Sm-Eu-Gd (SEG) carbonate.

5.2 Rare earth compounds

5.2.1
rare earth oxide
REO
compound containing one or more *rare earth elements* (3.1) and an oxygen element

Note 1 to entry: Generally, the formula is RE_xO_y where x is 2 and y is 3. However, several rare earth elements can exhibit valences other than 3, as shown in Table A.2.

Note 2 to entry: An individual REO dominantly contains one rare earth element, as shown in Table A.1. A mixed REO contains two or more rare earth elements.

Note 3 to entry: REO is in the form of powder. It is soluble in acid and is easily deliquesced.

5.2.2
rare earth chloride
compound containing one or more *rare earth elements* (3.1) and a chlorine element

Note 1 to entry: An individual rare earth chloride dominantly contains one rare earth element as a chloride. A mixed rare earth chloride contains two or more rare earth elements as chlorides.

Note 2 to entry: Rare earth chloride is usually of the massive state and is corrosive. It often contains crystallization water and is soluble in water. It will deliquesce after absorbing moisture. It can react with alkali, sodium sulfate or ammonium sulfate.

5.2.3
rare earth carbonate
compound containing one or more *rare earth elements* (3.1) and a carbonate ion

Note 1 to entry: An individual rare earth carbonate dominantly contains one rare earth element as a carbonate. A mixed rare earth carbonate contains two or more rare earth elements as carbonates.

Note 2 to entry: Rare earth carbonate is in the form of powder. It contains crystallization water and is soluble in acid. It will pyrolyze over 300 °C.

Note 3 to entry: Mixed rare earth carbonate is produced from *rare earth concentrate* (4.2.6), usually by a chemical process. It has a similar *rare earth distribution* (3.8) to raw materials.

5.2.4
rare earth hydroxide
compound containing one or more *rare earth elements* (3.1) and a hydroxide ion

Note 1 to entry: An individual rare earth hydroxide dominantly contains one rare earth element as a hydroxide. A mixed rare earth hydroxide contains two or more rare earth elements as hydroxides.

Note 2 to entry: Rare earth hydroxide can react with acid and CO_2. The hydroxide of trivalent cerium is unstable in the air and is easily oxidized into $Ce(OH)_4$. It will decompose over 200 °C.

EXAMPLE Lanthanum hydroxide, cerium hydroxide.

5.2.5
rare earth fluoride
compound containing one or more *rare earth elements* (3.1) and a fluorine element

Note 1 to entry: An individual rare earth fluoride dominantly contains one rare earth element as a fluoride. A mixed rare earth fluoride contains two or more rare earth elements as fluorides.

Note 2 to entry: Rare earth fluoride is in the form of powder and is corrosive. It contains crystallization water. It can react with alkali.

5.2.6
rare earth nitrate
compound containing one or more *rare earth elements* (3.1) and a nitrate ion

Note 1 to entry: An individual rare earth nitrate dominantly contains one rare earth element as a nitrate. A mixed rare earth nitrate contains two or more rare earth elements as nitrates.

Note 2 to entry: Rare earth nitrate is of the crystalline state. It contains crystallization water and is soluble in the water. It is easily deliquesced. It can react with alkali.

5.2.7
rare earth sulfate
compound containing one or more *rare earth elements* (3.1) and a sulfate ion

Note 1 to entry: An individual rare earth sulfate dominantly contains one rare earth element as a sulfate. A mixed rare earth sulfate contains two or more rare earth elements as sulfates.

Note 2 to entry: Rare earth sulfate is in the form of powder. It often contains crystallization water and is soluble in water. It can react with alkali.

5.2.8
rare earth oxalate
compound containing one or more *rare earth elements* (3.1) and oxalate

Note 1 to entry: An individual rare earth oxalate dominantly contains one rare earth element as an oxalate. A mixed rare earth oxalate contains two or more rare earth elements as oxalates.

Note 2 to entry: Rare earth oxalate is of the crystalline state and is corrosive and toxic. It contains crystallization water. It will decompose over 800 °C and transform to oxide.

5.2.9
rare earth phosphate
compound containing one or more *rare earth elements* (3.1) and a phosphate ion

Note 1 to entry: An individual rare earth phosphate dominantly contains one rare earth element as a phosphate. A mixed rare earth phosphate contains two or more rare earth elements as phosphates.

5.2.10
rare earth sulphide
compound containing one or more *rare earth elements* (3.1) and a sulphur element

Note 1 to entry: An individual rare earth sulphide dominantly contains one rare earth element as a sulphide. A mixed rare earth sulphide contains two or more rare earth elements as sulphides.

Note 2 to entry: Rare earth sulphide is in the form of powder. It is easily deliquesced. It can react with acid.

5.2.11
rare earth acetate
compound containing one or more *rare earth elements* (3.1) and acetate

Note 1 to entry: An individual rare earth acetate dominantly contains one rare earth element as an acetate. A mixed rare earth acetate contains two or more rare earth elements as acetates.

Note 2 to entry: Rare earth acetate is of the crystalline state. It contains crystallization water and is soluble in the water. It can absorb the moisture. It can react with alkali.

5.2.12
rare earth citrate
compound containing one or more *rare earth elements* (3.1) and citrate

Note 1 to entry: An individual rare earth citrate dominantly contains one rare earth element as a citrate. A mixed rare earth citrate contains two or more rare earth elements as citrates.

Note 2 to entry: Rare earth citrate is in the form of powder. It contains crystallization water and is soluble in the water. It can react with alkali.

5.2.13
rare earth hexaboride
compound containing one or more *rare earth elements* (3.1) and a boron element

Note 1 to entry: Hexaboride is obtained by reducing *rare earth oxide* (5.2.1) by boron carbide (or pure boron).

6 Terms related to the rare earth production process

6.1 Production of rare earth concentrate

6.1.1
production of rare earth mineral concentrate
process used to separate *rare earth minerals* (3.2) from *rare earth ores* (3.3) and concentrate rare earth minerals by beneficiation and other physical and physico-chemical methods

6.1.2
production of ion adsorption concentrate from ion adsorption clay
process used to extract rare earth ions from the ion adsorption clay *rare earth minerals* (3.2) by chemical methods and either precipitate the rare earths as a high grade mixed rare earth precipitate or concentrate the rare earths into a high concentration solution

6.2 Rare earth hydrometallurgy

6.2.1
decomposition of rare earth ore or concentrate
process used to attack *rare earth ore* (3.3) or concentrate by hydrometallurgical means and leach the *rare earth elements* (3.1)

Note 1 to entry: The methods used include acid and alkali processes and may be preceded by, or accompanied by, pyrometallurgical processing to improve the amenability of the ore or concentrate to extraction.

6.2.2
rare earth separation
process used to separate a mixture of *rare earth elements* (3.1) into individual rare earth elements or groups of elements

Note 1 to entry: Rare earth separation mainly adopts such process as solvent extraction, ion-exchange, fractional crystallization, oxidation/reduction, ion exchange chromatographic separation, high performance liquid chromatography, electrophoresis, molecular recognition and electrowinning. Of these, solvent extraction is most commonly used on a commercial scale. Separation results from differences in the distribution coefficients of various rare earth ions.

6.2.3
precipitation process
process for recovering solid rare earth compounds from an aqueous solution by adding a suitable chemical reagent

6.2.4
rare earth compound roasting
processing of rare earth compounds at elevated temperatures to obtain *rare earth oxides* (5.2.1)

Note 1 to entry: Roasting operations have been used to treat rare earth compounds such as carbonate, hydroxide and oxalate to produce rare earth oxides.

Annex A
(informative)

Characteristics of rare earth elements and individual rare earth oxides

Table A.1 — Rare earth elements

Name	Symbol	Characteristics
Lanthanum	La	A silvery metallic element belonging to group 3 (formerly IIIA) of the periodic table. Its principal ore is bastnaesite, from which it is separated by an ion exchange process. There are two natural isotopes, lanthanum-139 (stable) and lanthanum-138 (half-life 10^{10} to 10^{15} years). The metal, being pyrophoric, is used in alloys for lighter flints and the oxide is used in some optical glasses. The largest use of lanthanum, however, is as a catalyst in cracking crude oil.
Cerium	Ce	A silvery metallic element that occurs in allanite, bastnaesite, cerite and monazite. Four isotopes occur naturally: cerium-136, -138, -140 and -142; 15 radioisotopes have been identified. Cerium is used in mischmetal, a rare earth metal containing 25 % cerium, and in lighter flints. The oxide is used in the glass industry.
Praseodymium	Pr	A soft silvery metallic element found in bastnaesite and monazite. The only naturally occurring isotope is praseodymium-141, which is not radioactive; however, 14 radioisotopes have been produced. It is used in mischmetal, a rare earth alloy typically containing 5 % praseodymium, and in lighter flints. Another rare earth mixture containing 30 % praseodymium is used as a catalyst in cracking crude oil. It is a valuable component of NdFeB permanent magnets.
Neodymium	Nd	A soft silvery metallic element that occurs in bastnaesite and monazite. There are seven naturally occurring isotopes, all of which are stable, except neodymium-144, which is slightly radioactive (half-life 10^{10} to 10^{15} years). Seven artificial radioisotopes have been produced. The metal is used to colour glass violet-purple and to make it dichroic. It is also used in mischmetal (18 % neodymium) and in neodymium-iron-boron alloys for magnets.
Promethium	Pm	A soft silvery metallic element with only naturally occurring isotope, promethium-147, which has a very short half-life of only 2,52 years. Eighteen other radioisotopes have been produced, but they have very short half-lives. The only source of the element is nuclear-waste material. Promethium-147 is of interest as a beta-decay power source but the promethium-146 and -148, which emit penetrating gamma radiation, must first be removed.
Samarium	Sm	A soft silvery metallic element, Sm occurs in monazite and bastnaesite and some ionic clay ores. There are seven naturally occurring isotopes, all of which are stable except samarium-147, which is weakly radioactive (half-life $2{,}5 \times 10^{11}$ years). The metal is used in special alloys for making nuclear reactor parts as it is a neutron absorber. Samarium oxide (Sm_2O_3) is used in small quantities in special optical glasses. The largest use of the element is in the ferromagnetic alloy $SmCo_5$, which makes permanent magnets that are several times stronger than most other materials.