Past experience of environmental, health and safety issues in REE mining and processing industries and an evaluation of related EU and international standards and regulations

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1. Introduction

Rare Earth Element (REE) mining, processing and exploitation are large scale industries that use a wide range of chemical substances and generate significant quantities of waste. Additionally, the ores contain variable amounts of impurities such as non-target toxic metals, fluorine and radionuclides that may be released from the ore during processing into the product or waste streams, and/or represent safety issues to the workers.

Past REE mining and processing has led to significant environmental impacts in several non-EU countries. However, the EU has a wide range of environmental protection legislation that should encompass the activities involved in the mining and processing of REE. Equally, the radiological hazards associated with handling and disposal of radionuclide-bearing REE ores and tailings should in theory be regulated adequately by existing EU regulation. This report therefore examines the current EU regulations in terms of their application to REE mining and processing, and evaluates the extent to which the regulatory regime is prepared to support the development of a sustainable REE industry in Europe.

The report structure is as follows:

- Section 2 introduces the REE mining and processing sites discussed in this report
- Section 3 describes the environmental and health impacts experienced at and around REE mining and processing sites, and identifies the main radionuclide and hazardous chemical release pathways
- Section 4 summarises existing EU legislation that is relevant to the REE mining and processing industry
- Section 5 examines the best available techniques reference documents from the perspective of REE mining and processing
- Section 6 compares EU and international legislation in some key aspects of protecting the environment and human health protection
- Section 7 concludes on the state of EU legislation and identifies areas that should be considered further to support the development of a sustainable REE industry in Europe

2. REE mining and processing sites

In this section, a brief introduction is given to the mining and processing sites discussed in this report. The sites discussed are located in Australia, Brazil, China, India, Malaysia, Russia and Soviet Union, and the USA.

2.1. Australia

The Mount Weld REE deposit is located in Western Australia, 35 km south of Laverton. The deposit is hosted by Mount Weld carbonatite, a circular intrusive igneous complex approximately 3 km in diameter. The Mount Weld mine is operated by Lynas Corporation Ltd. The ore contains on average 0.075 % ThO_2 and 0.003 % U_3O_8, corresponding to average activity concentrations of 2.7 Bq g^{-1} ^{232}Th and 0.3 Bq g^{-1} ^{238}U (IAEA, 2011).

The ore concentration process at Mount Weld involves crushing, grinding and flotation, and the plant handles both water treatment and residue management. The Mount Weld REE concentrate contains 0.13-0.16 % thorium and 0.0021-0.0029 % uranium (IAEA, 2011). Thorium and uranium decay series radionuclides are in secular equilibrium in the concentrate. Since the sum of the activity concentrations of ^{232}Th and ^{238}U is less than 10 Bq g^{-1}, the concentrate falls outside the scope of the IAEA Regulations for the Safe Transport of Radioactive Material and can therefore be transported as non-radioactive material (IAEA, 2011). The average activity concentration of ^{232}Th in the tailings is 1.8 Bq g^{-1} (IAEA, 2011).

The mining and concentration of REE ore at Mount Weld is followed by shipment of the concentrate to a REE processing facility (LAMP) at Gebeng, Pahang State, Malaysia, where further processing take place to produce high purity REE compounds (IAEA, 2011). The concentrate has been processed at the Lynas Advanced Materials Plant (LAMP) since June 2013 (Lynas, 2013).

2.2. Brazil

In Brazil, monazite sand with a ThO_2 content of ~6% was processed for REE from 1949 – 1992 (da Costa Lauria and Rochedo, 2005). The first stages of REE processing were carried out at the Santo Amaro Mill (USAM) located in a densely populated residential district of São Paulo City. The process used (Figure 2-1) included two steps that precipitated concentrated radioactive wastes. The separation of the light and heavy REE was then carried out at the Interlagos mill site (USIN), located in an industrial area of São Paulo city. Storage facilities were built in Botuxin, a rural location of São Paulo state, to house the wastes. In the absence of radiation protection regulations, radioactive residues were handled, transported and stored inappropriately, and were used to stabilise swampy land. As a result, the two processing sites in São Paulo city required remediation and the waste storage site is under investigation (da Costa Lauria and Rochedo, 2005).

2.3. China

China dominates the world's REE mining and production, producing over 130 000 tons of REE in 2008 alone (Paul and Campbell, 2011). The export volume of rare earths from China increased gradually from 1979 until 2006, when the volume reached a peak with 57,400 tons and then declined from 2007 onwards.

Operations range from large government-owned facilities to small illegal sites. Illegal exports from China may amount to 20,000 tons of REE oxide per year (Öko Institut, 2011). Often, smaller operations have little or no environmental controls in place, and larger operations have only recently begun adopting such measures (US Environmental Protection Agency, 2012a).

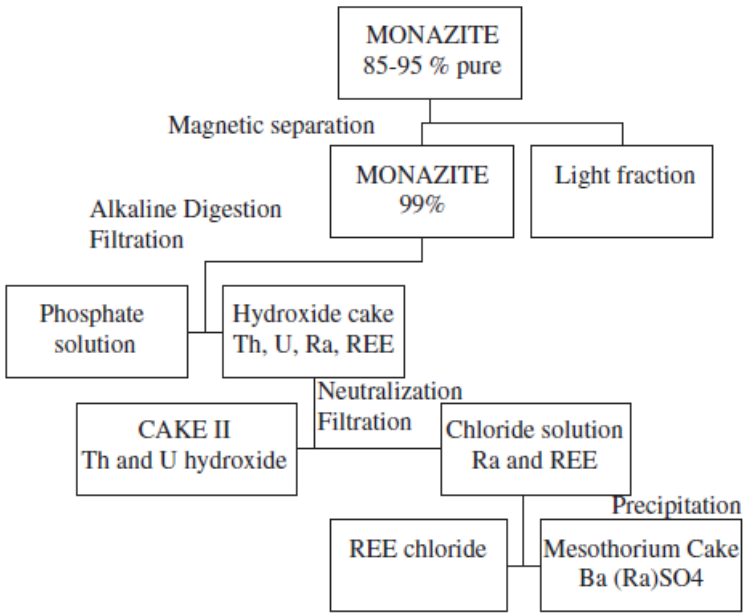

Figure 2-1 Basic steps of the monazite chemical processing performed in USAM (da Costa Lauria and Rochedo, 2005)

The **Bayan-Obo mine**, Inner Mongolia is the largest rare earth mine in the world although the main product is iron (British Geological Survey, 2011). After more than 40 years of mining, the main and east ore bodies have been heavily exploited (MEP, 2011). In the operation period up to 2005, the recovery rate of mineral resources was less than 10%. Present recovery rates of mineral resources may be higher, at around 60% by state-owned and 40% by privately-owned enterprises (Bo, 2009 cited in Schüler et al., 2011). Although the ore concentrate contains thorium (0.15-0.4% Th; IAEA, 2011), this has not been utilised (MEP, 2009 cited in Schüler et al., 2011). The Chinese Draft of Emission Standards of Pollutants from Rare Earths Industry (MEP, 2009 cited in Schüler et al., 2011) indicated that the amount of tailings from the iron and rare earth mining in Bayan Obo has reached 150 million tons. Despite the risks associated with tailings dam failure, the authorities have decided to stock the tailings. The relatively rich REE content of the tailings means that they are a potential raw material for future exploitation when a more efficient extraction method becomes available. Therefore, they are transported to the impoundment/reservoir for the whole mining operation (iron ore and rare earth concentration plants), which covers an area of eleven square kilometres.

Rare earths are extracted from ion-adsorption type deposits in the Longnan district, Jiangxi province, in southern China (Investorintel.com, 2012). An in-situ leaching method is used, in which holes are drilled into the ore deposit and leaching solution is pumped in. The solution bearing the dissolved ore components is then pumped to the surface and processed. The Chinese government regards the in-situ leaching technology as more environmentally sound than other leaching technologies such as pond and heap leaching (MIIT, 2010 cited in Schüler et al., 2011). The use of a carbonate leach solution has a lower environmental impact, because the use of acids in unsuitable locations can lead to groundwater contamination, and groundwater restoration after acidic leaching is difficult (NEA/IAEA, 1999). The ion-adsorption type ores are particularly suited to in-situ leaching, due to the relative ease with which the REE can be extracted. However, this also makes it possible for small firms to be involved, including illegal operations (Investorintel.com, 2012). In-situ leaching is not considered appropriate for REE mining in the USA because of the lack of suitable sites, the likely need

for an acidic leach, the low solubility of REE and the potential contamination of groundwater (US EPA, 2012a). The southern Chinese ores have low associated radioactivity.

2.4. India

Beach sand in India contains a range of economic minerals and is mainly mined by dredging, although dry mining also takes place (IREL, 2013b). Some of the minerals, notably monazite, contain high levels of both REE and Th. Thorium is an asset for future Th-fuelled nuclear reactors in India, thus these minerals are "prescribed substances" under the Atomic Energy Act, 1962 and are reserved for use in the public sector under the Policy on Beach Sand (1998; SIPCOT, 2013). Although private companies can mine beach sands for other minerals under licence from the Department of Atomic Energy (Government of India Department of Atomic Energy Public Awareness Division, 2012), monazite has to be returned to the beach in the tailings or stockpiled. The publically owned Indian Rare Earths Limited (IREL) is the only company in India with a licence to mine and process monazite (Government of India Department of Atomic Energy Public Awareness Division, 2012). IREL produce Th compounds, REE chlorides and trisodium phosphate from monazite (IREL, 2013a).

The Indian government recently approved a policy to encourage sand mineral exploitation through a mixture of public and private investment, including foreign investment (SIPCOT, 2013). This policy aims to upgrade the technologies to meet international standards and to add value to the process through improved products. Additionally, Toyota Tshusho Corp and Indian Rare Earths Limited have agreed a joint venture to export monazite to Japan for REE extraction.

2.5. Russia/Soviet Union

At present, rare earth metals are produced from the Lovozero deposit on the Kola Peninsula in the northwest of Russia (Zaitsev and Kogarko, 2012). In addition, scandium by-product recovery started in the Dalur uranium mine in February 2013.

Russia is currently the world's sixth largest uranium producer, accounting for 5 % (2 872 tU in 2012) of world output from three mines: Priargunsky, Dalur and Khiagda. The Priargunsky mine is the largest producer of U and uses underground mining together with conventional hydrometallurgical processing methods. Approximately 30 % of Russian uranium is produced by in-situ leaching (ISL) in Dalur and Khiagda mines. During the Soviet period, uranium was mined at a large number of sites in Russia and Eastern Europe. Russian mining and legacy sites provide insight into public exposure to radioactivity and environmental contamination that have relevance for NORM-rich REE sites. Therefore relevant information has also been gathered relating to these sites.

2.5.1. Lovozero REE mine

The Lovozero REE mine on the Kola Peninsula has been mined for over 50 years (Castor and Hedrick 2006). The Lovozero deposit is hosted by nepheline syenites in the peralkaline Paleozoic Lovozero massif, and loparite [$(Ce,Na,Ca)_2(Ti,Nb)_2O_6$] is the major REE ore mineral. The ore contains 2-3 % loparite and total REE content in the loparite is 28-37 % (IAEA, 2011). The main rare earth metals of the ore are cerium, lanthanum, neodymium and praseodymium. In addition to REE, titanium, niobium and tantalum are produced.

The Lovozero ore is mined using underground and open pit methods. Beneficiation involves size reduction, gravity separation and electromagnetic separation, which yield a 95 % loparite concentrate (IAEA, 2011). The mine produces about 6000 tonnes of loparite per year (Zaitsev and Kogarko, 2012) and the mine plans to double production by the year of 2015. Additionally, there are plans to improve the ore dressing and extraction of REE from apatite and eudialyte (Zaitsev and Kogarko, 2012).

The loparite concentrate contains 0.5-1.0 % ThO_2 and 0.02-0.03% U_3O_8. Assuming secular equilibrium and representative ThO_2 and U_3O_8 concentrations of 0.6 and 0.03 %, respectively, the activity concentrations of the concentrate are 21 Bq g^{-1} ^{232}Th and 3 Bq g^{-1} ^{238}U (IAEA, 2011). To estimate the activity concentrations in the ores, the IAEA (2011) assumed that the concentrations were 40 times lower than the concentrate, corresponding to 0.5 Bq g^{-1} ^{232}Th and 0.08 Bq g^{-1} ^{238}U.

The loparite concentrate is shipped from Lovozero to Solikamsk Magnesium Plant in Perm Krai for further processing and REE extraction. The Solikamsk plant exports and delivers most of the REE intermediate products to Estonia (Molycorp Silmet in Sillamäe) and Kazakhstan (Irtysh) for REE separation (IAEA, 2011).

2.5.2. Sillamäe processing plant

The Sillamäe Oil Shale Processing Plant in Estonia was originally used to produce uranium after the Second World War. In 1970, tantalum, niobium and REE production from the Lovozero loparite concentrate started at the plant and operation continued until the demise of the Soviet Union, at the end of 1991 (Lippmaa et al., 2006). In total, 152 379 tonnes of the Lovozero loparite concentrate was treated at the plant, producing 48 676 tonnes of LREE trioxide mixture (Lippmaa et al., 2006). Cerium, lanthanum and neodymium were also separated, purified in extraction cascades and sold as fluorides.

A mixture of sulphuric and hydrofluoric acids was used to extract REE from the loparite concentrate. Most of the niobium, tantalum and rare earths dissolve in the acid, but thorium remains as insoluble fluoride precipitate in the “thorium cake” (2.5 % ThO_2 equivalent). This precipitate also contains about 27 % barium sulphate, with co-precipitated ^{228}Ra, 12 % REO, 6.8 % fluorine, 3 % titanium dioxide, 3.7 % calcium oxide and 7.9 % silica (IAEA, 2011). The precipitate was deposited in the waste facility along with other waste (Lippmaa et al., 2006).

2.5.3. Dalur mine

The production of REE as a by-product of uranium mining is imminent at the Dalur mine, in the Kurgan region of the Transural uranium district. This site applies in-situ leaching and scandium dissolves in the leach solution along with uranium. In February 2013, the pilot plant for the production of the scandium concentrate came into operation (Basov, 2013). The concentrate will be delivered to a processing plant in Lermontov for final treatment and the manufacture of 99.9 % scandium oxide and aluminoscandium alloy. Production is expected to increase from 24.5 tonnes of scandium concentrate in 2013 to 134 tonnes in 2023 (Basov, 2013).

2.5.4. Kostousovo legacy site

The Kostousovo legacy site is located in Ozerny in the Urals, 70 km northeast of Yekaterinburg. A monazite sand processing facility operated here to support the nuclear and military industries between 1949 and 1964 (Yarmoshenko et al., 1996). Kostousovo village is located 3 km south of Ozerny.

2.5.5. Priargunsky

The Priargunsky Mining-Chemical Production Company (PPGHO) operates in the Chita region of the Russian Federation (NEA/IAEA, 1999) and is responsible for mining Russia’s most extensive uranium ore region, Streltsovsky. The Streltsovsky uranium ore region covers an area of 150 km^2 and has 19 uranium deposits with an average grade of about 0.2% U. Mining began in the area in 1974 using open pits and underground mines and the annual uranium production is about 2500 tonnes (NEA/IAEA, 1999). Uranium is leached from the ore using sulphuric acid at a hydrometallurgical plant and is recovered by ion exchange. Since the 1990s, low grade ores have been processed using heap

leaching. The town of Krasnokamensk (population 60 000) lies approximately 10-20 km away from PPGHO.

2.5.6. Khiagda uranium mine

The Khiagda uranium mine is located in the Bauntovsky District of the Republic of Buryatia and has been active since 1999. In-situ leaching is applied and the leachate is processed into uranium concentrate (yellow cake). The production volume increased by 24.8% to 332 tons of uranium between 2011-2012 (JSC Khiagda, 2013).

2.6. United States

2.6.1. Mountain Pass

The Mountain Pass deposit in California was discovered by a uranium prospector in 1949 and the Molybdenum Corporation of America bought the mining claims. The Mountain Pass mine and refinery began operation in 1952 and production expanded greatly in the 1960s in response to the demand for europium to make colour television screens. Between 1965 and 1995, the mine supplied most of the world wide rare earth metals.

The Molybdenum Corporation of America became Molycorp in 1974. The corporation was acquired by Union Oil in 1977, which in turn became part of Chevron Corporation in 2005. Before 1980, wastewaters were disposed of using percolation-type surface impoundments and this, along with conventional tailings management, impacted on the groundwater quality (US EPA, 2012a). Two off-site evaporation ponds were built (1980, 1987) and waste waters were pumped to these for disposal. These pipelines failed on many occasions leading to soil contamination, including two notably large volume spills in 1989 and 1990. The first of these major spills also released tailings (US EPA, 2012a).

The mine closed in 2002 in response to both environmental restrictions and lower prices for REEs. The processing of previously mined ore continued at the site while the mine was inactive. In 2008, Chevron sold the mine to Molycorp Minerals LLC, a private company formed to revive Mountain Pass. In December 2010, Molycorp announced that it secured all the environmental permits and active mining recommenced in December 2010.

2.6.2. South Maybe Canyon

The South Maybe Canyon Mine Site, in the Blackfoot River Sub Basin, Idaho, was developed for the production of phosphate, and REEs were recovered as a by-product. The mine closed in 1983. In 1996, six horses in a field downstream from the site were diagnosed with selenium toxicosis and an Administrative Order of Consent for a site investigation was entered into by the U.S. Forest Service and Nu-West Mining, Inc. in 1998 (United States Department of Agriculture Forest Service Region 4, 1998).

This mine has also been identified as a possible source of REEs for future development (US EPA, 2012a)

2.6.3. Pea Ridge

The Pea Ridge Mining Operation, Missouri was mined for iron ore for about 40 years. The former owners of Pea Ridge had, however, planned to produce REE as a by product of the process and had also identified an adjacent ore body that they had planned to mine primarily for REE. In 2010, the EPA imposed administrative penalties for violations of the Clean Water Act at the site (US EPA, 2012a). A new company, Pea Ridge Resources, now owns the site and began a mine feasibility study in 2012.

Pea Ridge has a relatively small heavy REE deposit but the ore potentially has higher concentrations than any other deposit. There is also the possibility of using old tailings as a source of REE (US EPA, 2012a).

3. Past experience of environmental impacts from REE mining and processing

Previous experience of REE mining allows us to examine the main pathways leading to environmental contamination and human exposure to hazardous substances. In this Section, experience of radioactive contamination and radiological exposure are examined first, followed by chemical and physical hazards.

3.1. Radioactive contamination and radiological exposure

Human exposure to radiation has been one of the most widely documented concerns associated with past REE mining and processing activities, due to the high concentrations of U and Th and their daughter products that can be associated with REE ores.

To put the radiological doses discussed below in context, humans typically receive a background dose of 2-3 mSv a^{-1} from natural radioactivity although there are substantial global variations. The International Commission on Radiological Protection (ICRP, 2007) assume that there is a linear relationship between chronic doses from ionising radiation and occurrence of fatal cancer, with a 5% risk per 1000 mSv recieved. The most exposed members of the public must not receive > 1 mSv a^{-1} from all industrial activities, and this is limited in some countries to 0.3 mSv a^{-1} per industrial site. Workers can receive doses of up to 20 mSv a^{-1} if justified. However, a basic principle of radiation protection is that doses should always be kept as low as reasonably achievable. See Section 4.2 for more information on EU radiation protection regulations.

3.1.1. Australia

The International Atomic Energy Agency (IAEA, 2011) reviewed the typical doses received by Mount Weld mine workers and found them to be in the range 0.05–0.40 (max = 1.6) mSv a^{-1}, which is expected to increase to 0.3–0.8 (max <3) mSv a^{-1} after operations start. These doses would not require the workers to be registered as radiation workers. The tailings contain an average activity concentration of 1.8 Bq g^{-1} ^{232}Th and the IAEA (2011) suggests that they could be managed safely using suitable tailings management.

3.1.2. Brazil

The lack of radiation protection regulations for monazite processing and waste management in Brazil resulted in two processing sites in São Paulo city (USAM and USIN) requiring remediation and a waste storage site that is under investigation (da Costa Lauria and Rochedo, 2005; Section 2.2).

During decommissioning of the USAM site (1994-8), wastes were packaged and removed from the site; contaminated equipment, floors and walls were decontaminated before the buildings were demolished; and, soil was classified into different ^{228}Ra activity concentration categories for appropriate disposal. The dose criteria applied to site clearance for unconditional use was 1 mSv a^{-1} to the most exposed members of the neighbouring population, and scenario calculations were used to identify clearance values (National Report of Brazil, 2011). Therefore, soil with > 30 Bq g^{-1} ^{228}Ra was sent for storage at another site until a suitable disposal facility became available, soil with 0.65-30 Bq g^{-1} ^{228}Ra was disposed of at a municipal landfill site, and soil with < 0.65 Bq g^{-1} ^{228}Ra remained at the site (IAEA, 2011). Despite the remediation measures, there are still public concerns about the site (da Costa Lauria and Rochedo, 2005).

After work at USIN stopped in 1990, a radiological survey showed surface and deep soil contamination, with ^{228}Ra and ^{226}Ra concentrations between 153 to 33 000 and 50 to 6 500 Bq kg^{-1}, respectively (da Costa Lauria and Rochedo, 2005). The contamination arose from leakage of stored material and the use of the light fraction of monazite sand to stabilise swampy areas on site (National

Report of Brazil, 2006). Remediation here will involve the removal of an estimated 680 m^3 of contaminated soil, of which 80 m^3 will be classified as low level radioactive waste (National Report of Brazil, 2011). The classification of the contaminated soil will be based on the calculation of the total specific activity shown in Equation 1: soils with a total specific activity above 30 Bq g^{-1} will be classified as radioactive waste, while those below or equal to 30 Bq g^{-1} will be disposed of in a sanitary landfill. Soil with < 0.5 Bq g^{-1} ^{226}Ra and < 0.5 Bq g^{-1} ^{228}Ra will be used for land restoration (National Report of Brazil, 2011). The disposal activity limits are more stringent than the IAEA (2011) reported for USAM decommissioning wastes, due to the consideration of the total specific activity rather than just the activity of ^{228}Ra.

Total specific activity = 8 x ^{226}Ra (Bq g^{-1}) + 9 x ^{228}Ra (Bq g^{-1}) [Equation 1]

The Botuxin waste storage facilities were located in a basin containing wells and springs that supply the local inhabitants with water. Additionally, a brook that flows across the property contributes to the public water supply of a city that lies 12 km away. Since the Brazilian Nuclear Energy Commission did not regulate this kind of activity at the time, the radiological environmental impact was not considered in the site selection (Briquet et al., 2004). In total, the facility received 3500 t of waste (20 % thorium hydroxide and 1 % uranium hydroxides; ~1800 Bq g^{-1}) between 1975 – 1981. The waste was deposited in seven rectangular pools 3 m deep with 30 cm thick concrete walls (da Costa Lauria and Rochedo, 2005). A monitoring survey in 2000 determined up to 4.0 Bq L^{-1} ^{226}Ra in a site well, with average values of 0.1 Bq L^{-1} (cf. EU drinking water reference value of 0.5 Bq L^{-1} for ^{226}Ra; (Directive 2013/51/EURATOM) see Table 4-1). The same programme identified contaminated areas with soil activity concentrations of up to 70 000 Bq kg^{-1} ^{228}Ra, 890 Bq kg^{-1} ^{226}Ra and 13 000 Bq kg^{-1} ^{238}U (Briquet et al., 2004). Further characterisation of the site is required prior to clean up, including identification of the source of the high ^{226}Ra water concentrations (da Costa Lauria and Rochedo, 2005).

3.1.3. China

The ore concentrates at Bayan Obo REE mine in China also have an elevated natural radioactivity (0.15-0.4% Th; IAEA, 2011), although lower than the Brazilian monazite sands. This has led to exposure of workers to radon isotopes via inhalation, and other Th-decay chain radionuclides through the inhalation of dust. The crushing process emits 61.8 t of Th containing dust per year (MEP 2009 cited in Schüler et al., 2011) and Chen et al. (2003) found a significant relationship between the inhalation of Th-containing dusts and lung cancer in miners in a 20 year study. Poor management of the dust has also led to offsite contamination, and the use of bricks made from process slag to build homes increased doses by 0.2 mSv a^{-1} (IAEA, 2011). The radioisotope concentrations in plants have also been found to be elevated by factor of 32, providing evidence of contamination in the Baotou region (MEP 2009 cited in Schüler et al., 2011).

3.1.4. India

Doses associated with beach sand mining are generally low, due to the low activity of the bulk sand (IAEA, 2011). Dust generation is also low for most sands. Exposure increases as the sand is processed and the monazite becomes more concentrated in the bulk material. Dust is created during dry separation of minerals and monazite may be more concentrated in the dust than the bulk material, due to its relatively soft structure.

The REE compounds manufactured from monazite generally contain low radionuclide concentrations. Haridasan et al. (2008) examined the gross alpha and beta activities of different types of REE compounds in India and they ranged from <0.5 to 18.1 and <0.5 to 22.4 Bq g^{-1},

respectively. The ^{228}Ra activity concentration in all the samples was below the exemption limit for regulatory purposes (Haridasan et al., 2008). Doses received by workers in the processing plant were also assessed and the average annual occupational dose was estimated to be 1.9 mSv. External gamma exposure and the inhalation of thoron progeny and long-lived alpha activity were identified as the major routes of exposure (Haridasan et al., 2008).

3.1.5. Malaysia

Malaysia's previous rare earth refinery in Bukit Merah, Perak state closed in 1992 following protests and claims that it was the cause of birth defects and leukaemia among nearby residents. The refinery is one of Asia's largest radioactive waste cleanup sites (U.S. Environmental Protection Agency, 2012a), costing a reported $100 million to deal with the radioactive and hazardous wastes.

Following on from this, the development and commissioning of the Lynas Advanced Materials Plant (LAMP) in Gebeng, Kuantan has met resistance. The Öko Institut, Germany, was commissioned by the "Save Malaysia Stop Lynas" campaign to review the safety of LAMP, and they criticised it on a number of levels (Öko Institut, 2013). Additionally, claims have been made that the regulatory system does not meet international standards, and that "Section 11 of the law allows the minister to direct regulators toward certain policies and so there's massive conflict of interest" (Malaysian Insider, 2013). Poor communication between the protestors and the Government, including information about the proposed waste disposal facility (Australian Network News, 2013), also appears to enhance distrust and unease.

Radionuclides concentrate in the beneficiation of the Mount Weld REE ore. Although the IAEA (2011) calculated doses to Australian mine workers, the doses to workers at LAMP, which was under construction at the time of the IAEA report, were not discussed. LAMP operates under a licence from the Atomic Energy Licensing Board (AELB) of Malaysia that stipulates that the residue must be returned to its source of origin (AELB, 2012). Despite this licence, there is still a lack of clarity over worker exposure and the fate of wastes.

3.1.6. Russia

Lovozero REE mine: No exposure data are available from Lovozero, but based on calculations for similar types of material and the activity concentrations given in Section 2.5.1, a worker exposed to loparite concentrate could receive an annual effective dose of ~4 mSv from exposure to external gamma radiation and ~2 mSv from exposure to airborne dust (IAEA, 2011). Such a situation would require the implementation of an occupational radiation protection program. For a worker exposed only to ore, the corresponding annual effective doses would be about 0.1 and 0.05 mSv for gamma radiation and dust, respectively, and exposure control is not likely to be necessary (IAEA, 2011).

Sillamäe processing plant: The Sillamäe processing plant in Estonia has a repository that contains wastes arising from both past uranium production and the later REE production. The thorium cake produced in REE processing was disposed of as a minor waste component in a repository together with other waste from uranium and loparite processing, and a large amount of oil shale ash from the local power plant (IAEA, 2011). The lower layer consists of black dictyonema shale processing waste from past uranium production and this is the most radioactive component of the repository, containing several kilograms of ^{226}Ra precipitated as the low solubility Ra-Ba sulfate (IAEA, 2011). The upper waste layer consists of thorium-rich loparite waste (Lippmaa et al., 2006); this is 5-10 m thick and contains 4 million tonnes of material (IAEA, 2011). IAEA (2011) state that the repository has been recultivated and declared not to pose a radiological hazard. The thorium concentration in the leachate from the repository is 5 µg/l, equivalent to a ^{232}Th activity concentration of 0.02 Bq L^{-1} (IAEA 2011). This is an order of magnitude lower than the drinking water standard for ^{228}Ra (0.2 Bq L^{-1}; Directive 2011/0074 (NLE) see Table 4-1), a short-lived daughter product of ^{232}Th that is more

radiologically hazardous upon ingestion. The concentrations suggest that long term storage or burial of this type of thorium residue can be regarded as an acceptable option, perhaps even for final disposal (IAEA, 2011).

Priargunsky Uranium Mine: Environmental contamination at the Priargunsky mine arises predominately from the tailings ponds of the hydrometallurgical and sulphuric acid plants. The tailings have a total volume of 300 million cubic meters and contain 9 000 Ci (3 x 10^{14} Bq) of radioactivity (NEA/IAEA, 1999). Elevated concentrations of radionuclides have been detected in ground water around the tailings pond and in mine water. The main challenges identified for the site were the increasing accumulation of radioactive liquid and solid wastes and, progressive contamination of natural surface and ground water systems by radioactive wastes (NEA/IAEA, 1999). These problems could lead to the contamination of the potable water supply. The first stage of remediating the mine water began in 1996 and was based on zeolite sorption technology (NEA/IAEA, 1999).

Radon inhalation was also found to be an important human exposure pathway; housing near the Priargunsky site was found to have indoor radon levels up to 28,000 Bq/m^3, about 190 times applicable indoor radon standards (Robinson, 1999).

Kostousovo legacy site: Monazite processing here resulted in the contamination of an area of ~10 000 m^2, mostly due to the storage of monazite sand, and the sand was used in the construction of buildings and roads without control (Yarmoshenko et al., 1996). ^{232}Th activity concentrations up to 6 Bq g^{-1} were determined in the contaminated zone (IAEA, 2011) and external gamma dose rates were up to 40-50 times higher than the local outdoor mean value. ^{220}Rn (the Rn isotope in the ^{232}Th decay chain) concentrations in buildings that were constructed from monazite-contaminated materials were between 2.5-15 Bq m^{-3}, compared with a maximum of 2.5 Bq m^{-3} in uncontaminated houses (IAEA, 2011).

3.1.7. International overview

The IAEA (2011) reviewed radiation protection and NORM residue management in the production of rare earths from thorium containing materials. The case studies involved different ore materials, with different radionuclide contents. However, the importance of dust control in the workplace was clear and additional measures, beyond the normal health and safety requirements, may be necessary in some cases to lower doses to workers. Dust is a particular issue for dry processing of radioactive materials. Worker awareness, good housekeeping and spillage control were also identified as important, along with monitoring the workplace and assessing the doses received by the workers. Radon (^{222}Rn, from the ^{238}U decay chain) and thoron (^{220}Rn; from the ^{232}Th decay chain) concentrations in the air increase in enclosed, poorly ventilated spaces, such as those used for storage of materials and can lead to elevated doses for workers in the area.

A review of doses received by workers in monazite processing plants in Brazil, France, India, Malaysia and the USA prior to 1993 showed that the annual dose for a worker exceeded the maximum permissible dose (during regulated work) of 20 mSv a^{-1} in a number of cases (IAEA, 2011). The highest doses were associated with working in mineral storage areas or near Ra removal circuits thus could be reduced by job rotation. The doses received are dependent on the radioactivity of the ores processed as well as the industrial processes involved, but clearly good practice can reduce these doses.

3.2. Chemical and physical hazards

In general, hard rock mining has the most significant environmental impact on surface water and groundwater quality (US EPA, 2012a). Therefore regulation of the management of tailings and waste waters is of particular importance. This is also apparent from the past experience of REE mining:

- The tailing impoundments at Bayan Obo, China, and Mountain Pass, USA have been identified as sources of environmental contamination (US EPA, 2012a)
- 75 m^3 of acidic waste water is generated for every tonne of REE produced at Bayan Obo and very significant amounts have been released (Hurst, 2010)
- Groundwater contamination occurred from the release of process wastewaters through percolation type surface impoundments at Mountain Pass, USA. The primary contamination was from high total dissolved solids, due to the neutralization of HCl with NaOH, but there were also low but detectable Ba, B, Sr and radiological constituents present. The groundwater is now being remeditated (US EPA, 2012a).
- Hazardous substances, including selenium, were released from the South Maybe Canyon Mine site into groundwater and surface water at concentrations that exceeded the Idaho state water quality standards (US EPA, 2012a)
- Metals and other constituents (oil and grease, copper, chromium, cadmium, iron, lead, and total suspended solids) were discharged from the Pea Ridge Mining Operation in Washington County, Missouri at concentrations that exceeded the permitted levels (US EPA, 2012a)
- Fluorine and thorium have dispersed into the waste waters of a concentration plant in Sichuan, China (Schüler et al., 2011)

Acidic tailings enhance leaching of hazardous substances; the tailings at Priargunsky uranium mine are acidic due to the sulfuric acid used in the process, thus a range of radionuclides and stable contaminants leach out and have been found to seep through the liner at the tailings handling facility (Robinson, 1999). In general, since REE ores do not tend to be sulfidic, acid mine drainage management *per se* is not a major concern. However, neutralisation of acid treated ore concentrates or carbonate minerals is important (Paul and Campbell, 2011).

Dust and gaseous emissions are also important vectors for both environmental contamination and the exposure of workers to toxic substances. For example, processing at Bayan Obo has led to the release of fluorine, dust, and waste gases containing HF and SO_2 (US EPA, 2012a).

An additional concern surrounding tailings heaps is the potential threat of the tailings pond dam failing. At Priargunsky, Russia, the waste ponds required reconstruction to lower the risk of flooding of the neighbouring valley and waste seeping into the rivers (NEA/IAEA 1999). Temporal changes in the depth of the water table can also be a concern for tailings management. In the main housing area near the Priargunsky site, the water table rose from depth of 19 meters in 1976 to 3-5 meters below ground surface in 1996 (Robinson, 1999).

In-situ leaching of uranium at Khiagda, Russia involved introducing high concentrations of sulfuric acid into the aquifer, and it did not appear that the planning stage had considered the later restoration of ground water quality (Robinson, 2001). Addressing these issues after the event is extremely expensive and/or difficult. Additionally, a significant and uncontrolled loss of control of the leaching chemicals occurred (Robinson, 1999), and the remediation of this type of contamination event is difficult (NEA/IAEA, 1999). Potential hazards associated with in-situ leaching are also apparent from the use of the technique at uranium deposits in Kazakhstan, which has contributed to

the need for an exclusion zone of 150 x 150 km in which the extraction of drinking water is forbidden (NEA/IAEA 1999).

With regard to LAMP in Malaysia, the Öko institute (2013) voiced concerns over the composition of the waste waters released, mainly the salt content and their discharge via open earth channels, and the use of gas and dust treatment systems that are not the best available techniques. They also raised the issue of the need to generate funds for site decommissioning and remediation, which is a prevalent concern in Malaysia after the $100 million required to remediate the Mitsubishi REE site in Bukit Merah.

4. EU standards and regulations

4.1. Current EU legislation

The mining and processing of REE falls within the scope of a wide variety of EU directives and regulations, as shown in Table 4-1. Directives and regulations are both forms of EU legislation, but while directives allow member states to formulate the actual laws that apply in their country, regulations are binding upon all member states.

Table 4-1 European legislation relevant to EURARE. The general name used for each piece of legislation in given in brackets.

Legislation	Title	Relevance
Related to radioactivity		
EC Directive 2013/59/EURATOM **(BSS, 2013)**	laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation	All materials used and created in the different stages of processing that have sufficient radioactivity to be considered radioactive. Updated BSS 1996 (96/29/EURATOM)
EC Directive 2013/51/EURATOM	laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption	Provides reference concentrations for radionuclides in drinking water based on a 0.1 mSv a^{-1} critical group dose limit. If more than one radionuclide is present, the sum of the concentration of each radionuclide divided by the relevant reference concentration should be less than or equal to 1.
Commission regulation (EURATOM) No 3227/76 and amendments 220/90 and 2130/93	Concerning the application of the provisions on Euratom safeguards	Control of nuclear materials (i.e. U, Th and Pu) to safeguard their use in civil applications
Related to chemicals and hazardous components		
EC Directive 2012/18/EU **(Seveso III)**	amending and repealing Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances (Seveso)	"operational tailings disposal facilities, including tailing ponds or dams, containing dangerous substances shall be included within the scope of this Directive"
EC regulation 1907/2006 of the European Parliament and Council **(REACH)**	concerning the registration, evaluation, authorisation and restriction of chemicals	All chemicals but not the ore or ore concentrates
EC Regulation No 1272/2008 of the European Parliament and of the Council **(Classification, Labelling and Packaging Regulation)**	on classification, labeling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (REACH)	Includes mineral ores and ore concentrates as well as the products
Related to waste management and emissions		
EC Directive 2006/21/EC of the European Parliament and Council **(Mining Waste Directive)**	on the management of waste from extractive industries and amending Directive 2004/35/EC (Environmental Liability Directive)	Waste resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries

Legislation	Title	Relevance
EC Decision 2009/360/EC	completing the technical requirements for waste characterisation laid down by Directive 2006/21/EC (Mining Waste Directive)	Waste characterisation
Directive 2010/75/EU **(Industrial Emissions Directive)**	on industrial emissions (integrated pollution prevention and control) (Recast)	Activities subject to these regulations include: "Processing of non-ferrous metals (2.5). Production of non-ferrous crude metals from ore, concentrates or secondary raw materials by metallurgical, chemical or electrolytic processes", and; " melting, including the alloyage, of non-ferrous metals, including recovered products and operation of non-ferrous metal foundries, with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals.". Radioactive substances are covered by the BSS and so are exempt
Directive 2008/98/EC **(Waste Framework Directive)**	on waste and repealing certain Directives	Wastes not covered by the Mining Waste Directive. Waste waters are out of scope, as they are covered by the Industrial Emissions Directive.
Directive 1999/31/EC **(Landfill Directive)**	on the landfill of waste	
Environmental and health protection regulations		
Directive 2000/60/EC **(Water Framework Directive)**	establishing a framework for Community action in the field of water policy	Important for the aqueous emissions and tailings management; addresses impacts off-site
Directive 2006/118/EC **(Groundwater Directive)**	on the protection of groundwater against pollution and deterioration	Important for aqueous emissions and tailings management
Directive 92/43/EEC **(Habitats Directive)** and Directive 2009/147/EC **(Birds Directive)**	on the conservation of natural habitats and of wild fauna and flora, and on the conservation of wild birds	Identify Natura 2000 sites (i.e. protected sites); "Mining projects in and around Natura 2000 sites are not automatically ruled out, but they must be appropriately assessed if likely to have a significant effect on a protected site. If such effects are expected, mining projects must either be avoided or amended"

Legislation	Title	Relevance
Directive 2003/87/EC **Emissions Trading System Directive**	establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC	Activities to which the directive applied include: "Metal ore (including sulphide ore) roasting or sintering, including palletisation", and "Production or processing of non-ferrous metals, including production of alloys, refining, foundry casting, etc., where combustion units with a total rated thermal input (including fuels used as reducing agents) exceeding 20 MW are operated"
Directive 2011/92/EU **(Environmental Impact Assessment Directive)**	on the assessment of the effects of certain public and private projects on the environment (codification)	Activities subject to these regulations include: "-Installations for the production of non-ferrous crude metals from ore, concentrates or secondary raw materials by metallurgical, chemical or electrolytic processes. -pit mines and quarries with a surface area exceeding 25 hectares"
Directive of the European Parliament and of the Council 2004/35/EC **(Environmental Liability Directive)**	on environmental liability with regard to the prevention and remedying of environmental damage	Polluter pays principle, prevention and remediation of environmental damage
Council Directive 98/83/EC **(Quality of Drinking Water Directive)**	on the quality of water intended for human consumption	Indicator parameters are listed for selected substances
Work place regulations		
Council Directive 89/391/EEC **(Health and Safety at Work Directive)** and later amendments	on the introduction of measures to encourage improvements in the safety and health of workers at work	
Council Directive 92/104/EEC	on the minimum requirements for improving the safety and health protection of workers in surface and underground mineral-extracting industries	Specifically for mining
Council Directive 92/91/EEC	concerning the minimum requirements for improving the safety and health protection of workers in the mineral- extracting industries through drilling	Specifically for drilling in the extracting industries
Directive 2002/49/EC **(Environmental Noise Directive)**	relating to the assessment and management of environmental noise	
Directive 2006/42/EC **(Machinery Directive)**	on machinery	

4.2. EU legislation for radioactive materials

The Directive controlling the use and disposal of radioactive materials has recently been updated (Basic Safety Standards (BSS) 2013/59/EURATOM). Issues related to naturally occurring radioactive materials (NORM) are addressed more explicitly in the new BSS than in the previous version (96/29/EURATOM). For example, the flexibility previously offered to member states to identify industries that result in worker exposure to NORM has been removed, in order to protect workers equally throughout the EU. The "activities in industries processing materials with naturally occurring radionuclides, or activities related to such processing" are within its scope, suggesting that REE mining and processing are relevant. This is already the case in the UK, where REE mining and processing are specifically identified as a NORM industry that falls under their national regulations. The new BSS also address worker exposure to radon explicitly, which will be important for both worker exposure and waste management in the REE industry.

As with all radioactive materials, REE ores with a NORM content below a specific level are exempt from regulation. However, if the radioactive content concentrates in certain process streams or wastes above the exemption level, the industrial process and waste management may require regulation. Conversely, for ores that require regulation, process streams and wastes may be cleared from regulation where the radionuclide content can be shown to be below the clearance level. See EURARE (2013) for further information on clearance.

Since the previous BSS (1996) directive was developed for small quantities of radioactive material, the EU also derived exemption and clearance levels for low concentration, large volume radioactive wastes (RP122 part I, 2000), and NORM wastes (RP122 part II, 2001; see Table 4-2). The exemption and clearance levels were derived from a range of potential exposure scenarios affecting workers and the general public. The updated BSS (2013/59/EURATOM) provide new regulatory exemption and clearance activity concentrations for NORM, which are based on natural radioactivity concentrations that exclude most natural soils from regulation.

Table 4-2 Relevant guidance documents and international safety guides related to radioactivity

Document	Title	Relevance
Guidance document: RP122 part I (2000)	Practical use of the concepts of clearance and exemption Part I: Guidance on general clearance levels for practices	Derivation of exemption limits and recommended clearance levels
Guidance document: RP122 part II (2001)	Practical use of the concepts of clearance and exemption Part II: Application of the concepts of exemption and clearance to natural radiation sources	Derivation of combined exemption and clearance levels for NORM from work activities
IAEA (2002)	Safety Guide on the management of radioactive waste from the mining and milling of ores	

Examples of radionuclide partitioning into different waste streams of REE processing are given in IAEA (2011), and show that Ra leaching and precipitation is of particular importance in terms of generating wastes with relatively high activity concentrations. It is essential that the REE salts and products are of sufficiently low radioactivity to be cleared from regulation by BSS. Where the NORM content of the ores requires regulation of materials, the operating licence will involve a justification of the safety of the procedures, including working practice and waste disposal, records to demonstrate that procedures are adhered to and monitoring of the work place and surrounding environment.

When U or Th are produced as by-products of the REE industry, the nuclear safeguards legislation (3227/76, 220/90, 2130/93) is relevant. This regulates the control of materials that are capable of undergoing nuclear fission, or being used to produce a fissile isotope. Uranium-235 is fissile, while both ^{238}U and ^{232}Th are fertile, i.e. can undergo neutron capture to form the fissile isotopes ^{239}Pu and ^{233}U, respectively. Transport of radioactive materials is regulated and the relevant international transport regulations are given in Table 4-3.

Table 4-3 International regulations and guidance on the transport of radioactive materials

Document	Title	Relevance
IAEA Regulations	Regulations for the Safe Transport of Radioactive Material, Specific Safety Requirements No. SSR-6 (Previously TS-R-1), 2012	Applies worldwide to all modes of transportation. Focuses on packaging, in order to provide safety under both normal and potential accident conditions.
UN Recommendations	Recommendations on the Transport of Dangerous Goods	Applies worldwide to all modes of transportation.
IMO Code	International Maritime Dangerous Goods Code, IMDG, 1965	Applies worldwide for carriage by sea of all types of dangerous goods. Addresses e.g. packaging and container stowage. For radioactive materials the basis is the IAEA Regulations.
ICAO Instructions	Technical Instructions for the Safe Transport of Dangerous Good by Air, 1981	Applies worldwide to air transport of all dangerous goods. Contains a list of dangerous goods, as well as requirements for packaging, marking, labelling and documentation fully consistent with the IAEA Regulations.
UN/ECE	European Agreement concerning the International Carriage of Dangerous Goods by Road, ADR, 2013	Applies to road transport in Europe. Contains requirements for the listing, classification, marking, labelling and packaging of dangerous goods. Consistent with the IAEA regulations.
OTIF Regulations	Regulations Concerning the International Carriage of Dangerous Goods by Rail, RID, 2013	These regulations constitute Appendix C of the Convention concerning International Carriage by Rail (COTIF). Applies to transport in contracting countries, i.e. primarily Europe, Kaukasus and parts of Middle East.

IAEA – International Atomic Energy Agency, UN – United Nations, IMO – International Maritime Organization, ICAO – International Civil Aviation Organization, UN/ECE - United Nations Economic Commission for Europe, OTIF - Intergovernmental Organisation for International Carriage by Rail

Depending on the doses received by workers at REE mine sites and processing plants, employees may need to be classified and treated as Radiation Workers. The four band system for the regulation of workplaces based on doses received is given in Table 4-4 (BSS, 1996).

The IAEA (2002) Safety Guide on the management of radioactive waste from the mining and milling of ores provides a useful flow chart that identifies the need for regulatory control to be in place, and for processes and waste management to be approved, prior to licensing. The drinking water reference values given for radionuclides in 2013/51/EURATOM may also be helpful with regard to developing waste management solutions, in that they indicate “far field” maximum potable water

concentrations. The IAEA Safety Guide (IAEA, 2002) also emphasises the importance of ensuring doses to the workforce are as low as reasonably achievable (ALARA), with social and economic factors being taken into account, which is a basic principle of radiation protection.

Table 4-4 ***Classification system for worker exposure***

Band	Regulation requirement	Effective dose (mSv a^{-1})	
		Normal scenario	Unlikely scenario
Band 1	No regulation necessary	**<1**	<6
Band 2	Lower level of regulation	**1-6**	6-20
Band 3	Higher level of regulation	**6-20**	20-50
Band 4	Process not permitted	**>20**	>50

4.3. EU legislation for mining and beneficiation

Szczepanski (2012) identified the European legislation used to regulate mining in general and this has been used as a basis for the discussion below. The Mining Waste Directive (2006/21/EC) is a key piece of legislation for REE mining, and links with the Water Framework Directive (2000/60/EC) and Groundwater Directive (2006/118/EC) for the management of mine water. The Quality of Drinking Water Directive (98/83/EC) may also be relevant, and lists several relevant indicator parameters. Seveso III (2012/18/EU) controls the management of tailings with respect to accident prevention, preparedness and response. As discussed in Section 3.2, contaminants associated with hard rock mining can have a significant environmental impact on surface water and groundwater quality. Therefore, these directives are of particular importance.

Dust and gaseous emissions are other important vectors for environmental contamination and worker exposure to toxic or radioactive substances (see Section 3.2). The Mining Waste Directive addresses these issues, as follows:

- The competent authority shall satisfy itself that the operator has taken the necessary measures in order to meet Community environmental standards, in particular to prevent, in accordance with Directive 2000/60/EC, the deterioration of current water status, inter alia, by:

  (a) evaluating the leachate generation potential, including contaminant content of the leachate, of the deposited waste during both the operational and after closure phase of the waste facility, and determining the water balance of the waste facility;

  (b) preventing or minimising leachate generation and surface water or groundwater and soil from being contaminated by the waste;

  (c) collecting and treating contaminated water and leachate from the waste facility to the appropriate standard required for their discharge

- The competent authority shall ensure that the operator has taken adequate measures to prevent or reduce dust and gas emissions

Industrial emissions arising from non-ferrous metal production from ores and concentrates, and thus from the beneficiation of REE ores, are within the scope of the Industrial Emissions Directive (IED; 2010/75/EU). The use of chemicals in mining and beneficiation is controlled by the REACH Regulation (1907/2006), and the ores and ores concentrates fall under the Classification, Labelling and

Packaging Regulation (No 1272/2008). All environmental legislation is strengthened by the Environmental Liability Directive (2004/35/EC), which is based on the “polluter pays” principle.

Pit mines and quarries with a surface area exceeding 25 hectares fall under the Environmental Impact Assessment Directive (2011/92/EU). Also, mining projects that are likely to have a significant effect on a Natura 2000 site, as defined by the Habitats Directive (Directive 92/43/EEC) and Birds Directive (2009/147/EC), require appropriate assessment prior to approval. According to the Environmental Liability Directive (2004/35/EC), the operator has a strict liability for damage to habitats and species that are protected by the Habitats and Birds Directives, and damage to water quality as defined by the Water Framework Directive (2000/60/EC). Mine workers are protected by two specific directives for mine workers (92/104/EEC and 92/91/EEC; Table 4-1), as well as the Health and Safety at Work Directive (89/391/EEC), Environmental Noise Directive (2002/49/EC) and the Machinery Directive (2006/42/EC).

4.4. EU legislation for processing and product development

The processing and manufacture of REE products will also be regulated by existing EU legislation. The chemicals used and products formed fall within the scope of the REACH Regulation (1907/2006), while the industrial emissions are controlled by the Industrial Emissions Directive (2010/75/EU) and the solid wastes by the Waste Framework Directive (2008/98/EC) and the Landfill Directive (1999/31/EC). The Water Framework Directive (2000/60/EC) and Groundwater Directive (2006/118/EC) are important with regard to aqueous emissions. Environmental impact assessment is required (2011/92/EU) and Seveso III (2012/18/EU) will control management with respect to accident prevention, preparedness and response if any chemicals are used in the processing that fall within its scope. The Emissions Trading Directive may have relevance, and the Environmental Liability Directive (2004/35/EC) again strengthens the other legislation with the “polluter pays” principle and the introduction of strict operator liability in certain cases.

More generally, the processed materials will need to conform to the Classification, Labelling and Packaging Regulations (1272/2008) and relevant workplace legislation includes the Health and Safety at Work Directive (89/391/EEC) and Machinery Directive (2006/42/EC).

The Industrial Emissions Directive lies at the centre of the environmental protection legislation from REE processing. The general principles are that:

(a) all the appropriate preventive measures are taken against pollution;

(b) the best available techniques are applied (see Section 5);

(c) no significant pollution is caused;

(d) the generation of waste is prevented in accordance with Directive 2008/98/EC;

(e) where waste is generated, it is, in order of priority and in accordance with Directive 2008/98/EC, prepared for re-use, recycled, recovered or, where that is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment;

(f) energy is used efficiently;

(g) the necessary measures are taken to prevent accidents and limit their consequences;

(h) the necessary measures are taken upon definitive cessation of activities to avoid any risk of pollution and return the site of operation to the satisfactory state defined in accordance with Article 22.

All industries are required to have a permit to operate that conforms to these principles. The regulations do not apply to research or development activities, or the testing of new products and processes.

5. Best available techniques reference documents

Best Available Techniques (BAT) can be defined as techniques that are most effective in achieving a high level of protection of the environment as a whole. In the EU, the integrated pollution prevention and control directive (IPPC; 96/61/EC) introduced the use of BAT to help control air, water and soil pollution. The BAT concept was also included in the recast of the IPPC directive (2008/1/EC), and then in the Industrial Emissions Directive (IED; 2010/75/EU), which superseded the IPPC directive.

Best available techniques reference documents (BREF) define BAT for specific industries and are based on an information exchange process across the European community. According to the IED (2010/75/EU), the purpose of BREF is to explore the techniques that are available and conclude which are BAT. BREF should be “descriptive rather than prescriptive” with a focus on driving forward improvements in environmental performance. They should also avoid any interpretation of the IED. Although the BAT conclusions in the BREF are not legally binding, they “should be the reference for setting permitting conditions” (IED; 2010/75/EU). They can, however, be supplemented with information from other sources.

5.1. Content of a BREF

Each BREF has a clearly defined scope and starts by describing the sector concerned, the relevant production processes currently applied and the measures taken to prevent or reduce emissions, and reports the current emission and consumption levels. Techniques that have been considered in the determination of BAT are then described, i.e. techniques that prevent emissions to air, water (including groundwater), and soil, or reduce these emissions, or prevent or reduce waste generation. The following information is required for each technique considered:

- Description
- Technical description
- Achieved environmental benefits
- Environmental performance and operational data
- Cross-media effects (i.e. relevant negative environmental effects due to implementing the technique)
- Technical considerations relevant to applicability
- Economics
- Driving force for implementation
- Example plants
- Reference literature

This information is used as the basis for determining BAT, which are reported as the BAT conclusions. The BREF presents the BAT conclusions in a prescribed way, to include the key information. Emerging techniques that have a good chance of becoming BAT in the future are also documented in a separate section.

5.2. Sevilla process

The creation or revision of a BREF document is carried out by an expert committee with an open exchange of information with stakeholders, following the Sevilla Process. The Sevilla Process is described in detail in a non-legislative EU Decision document (2012/119/EU). In brief, when the

Commission decides that a BREF document or update is required, it involves the IPPC bureau as a neutral, permanent and technically competent body to organise and support the information gathering process, and provide scientific and technical analysis of information. The IPPC bureau also has responsibility for writing the BREF. For BREF that are specified in legislation other than the IED, suitable alternative bodies can play this role. For example, the Council's sustainable production and consumption are responsible for the current update of the BREF on mining waste.

The commission also selects representatives of member states, industry and environmental non-governmental organisations (NGOs) to form a Forum. The main roles of the Forum are to give opinions on the process, ensure the quantity and quality of information gathered is sufficient and review two drafts of the BREF. The information gathering process is carried out by a technical working group (TWG), which consists of representatives of member states, industry, NGOs and the commission. The TWG also provides feedback on each draft of the BREF. The Forum evaluates the final draft and the process, and then publishes its opinions on the publically available updated final draft. BREF should be reviewed and updated at least every eight years.

5.3. BREF relevant to the REE industry

There are two BREF that are relevant to the REE mining and processing industries: the management of tailings and waste-rock in mining activities (EC, 2009) and the non-ferrous metal industry (EC, 2001). An update of the BREF for the non-ferrous metal industry (EC, 2001) is available as an official draft (EC, 2013).

The BREF for the management of tailings and waste-rock in mining activities (EC, 2009) provides generic BAT conclusions that are relevant across the sector. It is considered BAT to reduce the amount of waste, maximise the re-use of the waste material, for example as an aggregate, and to condition the tailings and waste rock within the process to minimise environmental or safety hazards. It is also BAT to apply life-cycle management, and to:

- Reduce reagent consumption
- Prevent water erosion
- Prevent dusting
- Carry out a water balance and using the results to develop a water management plan
- Apply free water management
- Monitor groundwater around all tailings and waste-rock areas

In terms of emissions to water is it BAT to:

- Re-use process water
- Mix process water with other effluents containing dissolved metals so that the finely ground tailings can absorb dissolved metals (favourable alternative to flocculation)
- Install sedimentation ponds to capture eroded fines
- Remove suspended solids and dissolved metals prior to discharge of the effluent to receiving watercourses
- Neutralise alkaline effluents with sulphuric acid or carbon dioxide
- Remove arsenic from mining effluents by the addition of ferric salts
- Apply one of a number of systems for neutralising acidic effluents

However, specific issues relating to the management of REE mining waste are not addressed in the BREF since REE mining does not currently take place in Europe. The experience of the REE mining industry does not contribute to the generic BAT conclusions. The management of NORM wastes is not included in the current BREF (EC, 2009) in any context either. The next update of this BREF will include uranium mining and so is expected to address BAT for minimising emissions of radionuclides and radiological exposure of workers. Although developments in European REE mining are not likely to be sufficiently advanced to contribute to the BAT conclusions in this update, they may be included as emerging techniques that are likely to become BAT in the future.

The BREF for the non-ferrous metal industry also provides generic environmental protection techniques for metallurgical processes (EC, 2001; EC, 2013) and emphasises the importance of re-use, recycling and recovery. However, since REE are not currently processed in Europe, these documents do not contain information on BAT for the REE industry. Equally, the issue of NORM in the beneficiated ore feedstock is not addressed, thus techniques for preventing or reducing the generation of radioactive waste and environmental emissions of radioactive materials are not included on any level. Exposure of workers to ionising radiation is also an important consideration.

6. Comparison of EU legislation with international legislation and practice

In this Section, examples of international legislation and practice are compared with EU legislation in areas of particular relevance to the REE industry. Russia, the USA and Western Australia are examined in detail because their history of mining, especially the mining of REE, would suggest that their legislation is relatively mature. Summaries of the relevant legislation are given in Appendices A-C.

6.1. Regulatory system and licensing

The historic lack of regulation, or inadequate regulation, of the REE mining and processing industry has led to widespread and long term environmental harm, and human exposure to harmful substances (see Section 3). Although China presents the most marked examples of this, almost every country with a history of REE mining or processing has its own examples of poor practice.

China's REE industry developed without due licensing and regulation and involved a large number of small companies, which created challenges with regard to price competition and over production as well as environmental impacts and human health. Illegal mining has been identified as a significant problem. To regain control, the Chinese government aims to consolidate the industry into a small number of state owned firms and have closed some smaller illegal producers, and merged larger producers. They also issued a white paper on the situation and policies of China's rare earth industry (Chinese Government, 2012). One of the main points was better coordination of rare earth utilisation with environmental protection, and the white paper referred to recent improvements in environmental legislation in general and for the REE industry in particular. An important aspect is the increased effort to enforce the regulations (MEP, 2011), although this may be challenging due to the legacy of environmental damage, the vast tailing heaps stored as a potential future reserve and the expectation of a degree of self-regulation.

Even when a regulatory system is in place, there can be challenges associated with eliminating illegal mining. India has a licence system for beach sand mining (SIPCOT, 2013) but the government of Tamil Nadu recently imposed a suspension on all river and beach sand mining pending an investigation into illegal mining and developing their policies further (Mining weekly.com, 2013). Furthermore, despite Russia developing legislation over the past two decades that in many cases meets or exceeds commonly accepted international standards, the enforcement of this legislation has been uneven (Josefson, 2012).

Environmental quality standards are an important tool in the regulatory system for planning as well as transparent interpretation of environmental monitoring results. These standards may vary from country to country but are generally available. In 2011, China brought in Pollutant Discharge Standards for the Rare Earth Industry, which sets the limits for the chemical oxygen demand, and emission of pollutants such as ammonia nitrogen, phosphorus, fluorine, thorium, heavy metals, sulfur dioxide, chlorine gas, and particulates for rare earth enterprises (Chinese Government, 2012). Australia has both federal and state water quality standards, while the USA has water quality standards in the Safe Drinking Water Act, state water quality standards along with guidance from the EPA. In the USA, emissions must be permitted by the National Pollutant Discharge Elimination System permit program (1972), under the Clean Water Act (1972). The priority substances for which water quality standards are defined in the EU's Water Framework Directive are not of particular relevance to the REE industry. However more extensive environmental quality standards for substances in soil, water and air are given in national legislation and guidelines, some as a result of EU directives. Amendments to the Groundwater Directive are also currently under discussion concerning: a) the

comparability of threshold values used by member states to define water status, and b) the inclusion of additional pollutants on the list of substances member states are required to provide threshold values for. The list currently includes cadmium, chloride, sulphate and conductivity, which have been identified previously in emissions from REE processing (see Section 3.2). The Quality of Drinking Water Directive (98/83/EC) and directive 2013/51/EURATOM for radioactive substances in drinking water list relevant indicator parameters or reference concentrations that are useful far field guidelines to apply in waste management strategies and permit requirements.

It is therefore clear that both regulation and implementation of the regulations are essential to protect workers, the public and the environment from the potential hazards associated with the REE industry. Past experience demonstrates that it is best practice to address the lifecycle of a facility within a licence application to ensure that the best approach is taken during the operational and closure phases, the impacts are considered and minimised, and a realistic assessment is made of the costs involved in adhering to environmental legislation. Although licensing in the EU is a national issue, the legislation discussed in Section 4 defines some licence requirements. Meaningful penalties for breaching licence conditions or operating without a licence are also required. In the EU, the Environmental Liability Directive is important legislation for encouraging good practice and minimising environmental damage. The “polluter pays” principle has also been introduced through legislation in other countries, for example the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in USA and the Contaminated Sites Act (2003) in Western Australia. The Contaminated Sites Act (2003) states the penalties associated with non-compliance, including a daily penalty to discourage delay.

6.2. Environmental impact assessment (EIA)

Environmental impact assessment is an increasingly common requirement for obtaining a mining licence, and mine sites with a surface area greater than 25 hectares are in scope of the EU’s Environmental Impact Assessment Directive. There is also a need for appropriate EIA if a proposed mine may impact a Natura 2000 site. In the USA, an EIA is a necessary component of the licence application if the area to be explored or mined is on or adjacent to federal land, or if the operations will discharge into surface waters (Clean Water Act, 1972; US EPA, 2012a). This has wide applicability since mine sites and associated facilities are large and are commonly built on a combination of federal and private land (National Academy of Sciences, 1999). Baseline environmental studies may also be required prior to licensing to determine the presence of sensitive species and habitats that might be impacted (e.g. Endangered Species Act, 1973).

In Russia, exploration and production of mineral resources also requires a licence that is regulated through the Subsoil Law (1992) and awarded by the Federal Agency for Subsoil Use (Rosnedra) (Josefson, 2012). The sub soil licence conditions specify environmental contamination limits and the licence can be terminated if there is an immediate risk to human health. The Environmental Expert Review Law (1995) and the Environmental Protection Law (2001) require that an EIA is carried out when a project may impact natural resources. The EIA needs to evaluate the possible adverse environmental impacts and ecological consequences and develop measures for decreasing or preventing adverse impacts. The construction and operation of various facilities are only permitted if the EIA is approved by the unified State Environmental Expert Review (Josefson, 2012). Additionally a mining allotment, land use permit and operating licence are required (Morozova, 2008).

In Western Australia, an Exploration Licence is required according to the Mining Act 1978 and then an EIA is required prior to mining under the Environmental Protection Act (1986). The first stage of this is an Environmental Scoping Document which, if approved and deemed necessary, would lead to a full EIA. A mining company may also be able to seek approval for mine developments in a given

region from the Environmental Protection Authority, as an alternative to the traditional mine-by-mine approach (Western Australia's EPA, 2013).

China is also bringing in an environmental risk assessment system for the REE industry, and increasing efforts to enforce the regulations (MEP, 2011).

6.3. Waste management

Waste management in the USA is controlled by the Resource Conservation and Recovery Act (1976), which protects human health and the natural environment from waste disposal. However, the Bevill amendment excludes wastes that are "uniquely associated" with mining and processing from regulation as hazardous wastes, and these are instead treated as non hazardous solid wastes.

The Contaminated Sites Act (2003) in Western Australia introduces three important principles relevant to waste management: polluter pays, full life-cycle costs and waste minimisation. The full life cycle costs principle means that the costs of effective waste disposal should be reflected in the price of the products. Tailing storage facilities in Western Australia are controlled by the Mine Safety and Inspection Act (1994), the Mining Act (1978), Environmental Protection Act (1986) and the Rights in Water and Irrigation Act (1914), along with other heritage and environmental conservation laws that may be relevant (Department of Mining and Petroleum, 2010). Specific guidelines are provided on the safe design and operating standards for tailings storage (Department of Mining and Petroleum, 1999) and for the management of NORM-containing tailings (Department of Mining and Petroleum, 2010; Figure 6-1)). The physical stability of tailings storage facilities and mining pits are of primary importance, thus flatter slopes are encouraged to minimise erosion and passive solutions are promoted to minimise the demands for long term management. The radioactivity of the wastes affects the stabilisation steps required, and a 50 cm cover layer of clay/soil is advised to limit emanation of radon gas and limit water percolation through the facility.

In the EU, waste facilities are required to have a permit by the Mining Waste Directive or Waste Directive, and the application for this includes a waste management plan for minimizing environmental impacts (EIONET, 2013). Facilities with a significant accident hazard also require an emergency plan to be drawn up by the competent authority. Additionally, the operator must provide a financial guarantee before operations start to ensure that the financial resources for restoring the waste facilities are always available. The operator must maintain the site until the competent authority approves site restoration and closure, and then the operator must maintain and monitor the site for as long as the competent authority considers necessary (EIONET, 2013).

6.4. Management plan for the post-closure or dormant periods

The importance of addressing closure and site rehabilitation at the licensing stage of REE mining is clear from the closure and rehabilitation issues associated with historic uranium mine sites worldwide (e.g. NEA/IAEA 1999). The better control throughout the lifetime of a plant, the lower the environmental contamination and the greater the relative ease of closure.

In the USA, the Surface Mining and Control Act of 1977 states that site closure must be planned in advance for mines located on federal lands, and that the land must be restored to the level where it can at least support the same uses as it did prior to mining (US EPA 2012a). This legislation was written for coal mining but is also relevant to REE extraction. Additionally, while the mine is idle, the waste piles, the tailings ponds, and other mine areas must be stabilized and managed. The Clean Water Act (1972) authorizes the National Pollutant Discharge Elimination System permit program (1972) which regulates point source discharges into surface waters. Groundwater is protected by the Safe Drinking Water Act (1974).

In Western Australia, according to the Mining Safety and Inspection Regulations (1995), a Project Management Plan must be written before operations start with details of the project and major risks and risk management strategies. If the mine plans to suspend, restart or cease operations, a notification must be submitted to the appropriate authority providing prescribed information on the precautions taken to ensure safety. If a mine is subject to the radiation safety part of the Mining Safety and Inspection Regulations (1995), a Radioactive Waste Management Plan is required in the initial licence application, including an outline proposal for the eventual decommissioning and rehabilitation of the mine. This plan should be updated at agreed intervals, and the final, detailed plan must be authorised separately before the site is decommissioned.

As discussed above, the EU Mining Waste Directive requires operators to provide a financial guarantee before operations start, and site closure is approved by the competent authority. Therefore, acceptable site management should be possible under likely scenarios not involving bankruptcy. The Seveso III legislation and the Environmental Liability Directive strengthen this further. Seveso III addresses operator responsibility to prevent major accidents, and the enforcement of the directive through regular inspections by competent authorities. Although Seveso III does not address mineral exploitation in mines, it does address operational tailings disposal facilities. However, the regulations controlling mine management during idle periods are not clear at an EU level. This reflects the issue that mine management, as opposed to mine waste management, is embedded in general EU environmental regulations rather than addressed directly.

6.5. Site management in the case of large scale accident or bankruptcy

The Contaminated Sites Act (2003) of Western Australia identifies that the Director of an insolvent company may be made liable for the costs of remediating land contaminated by the company. However, this is only the case if he or she is judged to have known about the activity that caused contamination and did not intervene, and that the company's insolvency is linked to avoidance of responsibility for site remediation. Ultimately, if the director is also bankrupt or not judged to be liable, the state takes responsibility. In the USA, CERCLA specifies that oil and chemical companies are taxed to create a "superfund" to pay for the EPA to clean up hazardous abandoned sites and respond to short term emergencies.

There is currently a discussion of a disaster risk-sharing fund in the EU to cover large scale industrial accidents (damage exceeding €100 million), funded by a mandatory insurance premium of a percentage of the annual net sales. An EC discussion document raise questions that need to be addressed for such a fund to be appropriate in light of the polluter pays principle (BIO Intelligence Service, 2013). The fund could not subsidise operators or it would be in breach of this principle, but if the funds are to be re-paid, there is the question of whether liability should be capped. Different industries have different levels of risk and there are differences in the extent to which environmental damage is covered by existing private insurance in different member states. These factors affect how such an EU fund should be defined.

The Non-Energy Extractive Industry Panel suggests that the fund is unnecessary in the EU, given the stringency of the Environmental Impact Assessment, Mining Waste, Seveso III, and Environmental Liability Directives, and the financial controls they define (Coppenholle et al., 2013). They argue that adherence to the EU law should make the fund unnecessary, and that the fund may encourage low standards in industry. However, environmental remediation after large scale accidents does need consideration and as does the management of sites and contaminated land that are no longer under ownership.

6.6. *Regulation of NORM wastes and residues*

The IAEA Basic Safety Standards (2014) include NORM explicitly, which is beneficial for the regulation of NORM in the REE industry globally. The current situation in the USA shows the complexity of managing NORM indirectly, since technologically enhanced NORM is regulated via the Clean Air Act (phosphate industry and uranium mines), the Clean Water Act (emissions of radioactive materials not specifically addressed under the Atomic Energy Act; Discharge limits for mines and mills), Safe Drinking Water Act (Maximum contaminant goal level for ionising radiation and U concentration limit) and CERCLA as a support (US EPA 2012b). There are also specific sub parts of the federal Ionizing Radiation Protection Program Regulations that specifically address NORM. Clear definition of NORM industries that are within scope of the regulations is an important step forward.

Countries with large scale NORM industries have developed their regulations for NORM wastes to a higher level than others, often taking lead from the UN, ICRP and IAEA. Norway has integrated its legislation for activities that involve or may involve radioactive pollution or radioactive waste management into its 2011 Pollution Control Act (Liland et al., 2012). This is appropriate, given the aim of the Act to "protect the outdoor environment against pollution and to reduce existing pollution, to reduce the quantity of waste and to promote better waste management". This Act controls the permit system.

NORM wastes in Norway are dominated by the offshore oil and gas industry, since Ra-rich scales form in the pipes that require regular removal and disposal. Ra-rich water has traditionally been discharged to sea and Norway is the largest emitter of Ra to the NE Atlantic. However, OSPAR aims to reduce discharges to sea and so the industry has been instructed to investigate possible on-shore water purification technologies (Liland, 2012). With regard to ^{226}Ra, a licence is required if the specific activity is > 1Bq g^{-1} or the total activity is > 1000 Bq $year^{-1}$. If the ^{226}Ra in the waste exceeds 10 Bq g^{-1} and the total activity is > 10 000 Bq $year^{-1}$, the waste must be disposed of in a repository (Liland et al., 2012). Wastes between 1 and 10 Bq g^{-1} are disposed of in a hazardous waste facility with a licence for radioactive waste. The Stangeneset repository has been built in Gulen municipality for the disposal of the higher activity wastes, i.e. with > 10 Bq g^{-1} of ^{226}Ra, ^{228}Ra or ^{210}Po. The repository is privately run, and the owners are required to have a fund for closure and remediation. The state has also guaranteed to manage the site if the company is no longer able. The system allows private companies to develop waste facilities and apply for a licence.

The UK also has specific guidance for the disposal of NORM wastes, again largely driven by the off-shore oil and gas industry. Here, NORM industrial activities are specified in the legislation and materials must arise from one of the industries and be above "out of scope" activity concentrations to require regulation. Wastes that are in scope can be disposed of in appropriate facilities based on their activity concentration and total activity (UK NIEA, SEPA and EA, 2013).

Environmental legislation in Australia is enacted at both a federal and state level, thus the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) publishes *Radiation Protection Series*, to guide state laws and promote good practice. The Codes of Practice documents are a part of this series and give prescriptive practice-specific radiation safety requirements. The Code of Practice and Safety Guide: Radiation Protection and Radioactive Waste Management in Mining and Minerals Processing (ARPANSA, 2005) is therefore highly relevant here. Additionally, the Western Australia Government's Department of Mining and Petroleum has written extensive guidelines for managing NORM in the mining and processing industry (see Figure 6-1). Compliance with these guidelines is recommended although they do not constitute the law. In South Australia, radioactivity is regulated by the Radiation Protection and Control (Ionising Radiation) Regulations (2000). However, since these regulations define 'radioactive ores' as those with a specific activity greater than 35 Bq g^{-1}, the mining, processing and waste disposal of lower activity ores are regulated through environmental

and mining laws. South Australia also has radiation protection guidelines for mineral exploration, including occupational radiation protection and waste management guidance for drilling operations in areas of known radioactive mineralisation, and when exploring for new uranium/thorium deposits (EPA South Australia, 2010).

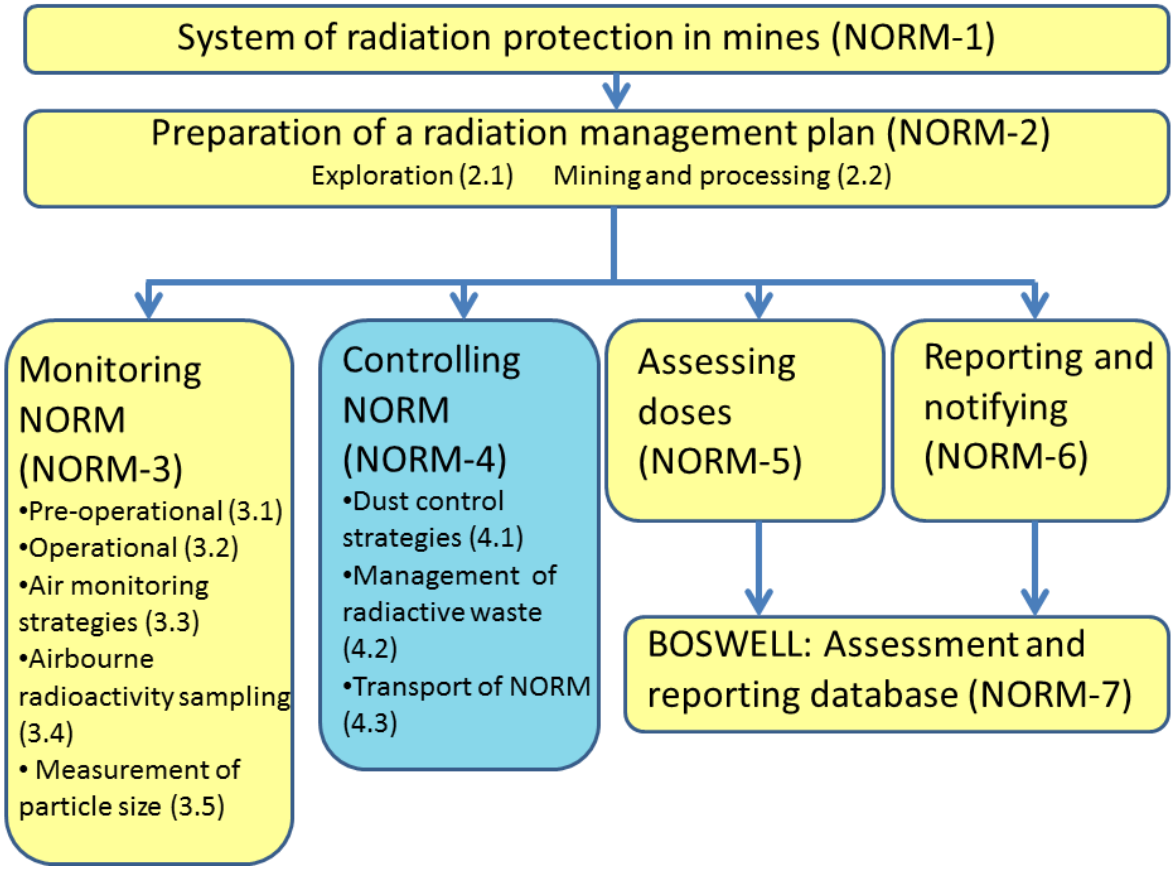

Figure 6-1 Overview of Western Australia's guidelines for managing NORM (Adapted from Department of Mines and Petroleum, 2010)

ARPANSA (2005) states that a Radiation Management Plan and a Radioactive Waste Management Plan must be written and approved prior to any work taking place that involves NORM. This is an integral part of the licensing system. One of the criteria for mines to be subject to the Radiation Safety part of Western Australia's Mining Safety and Inspection Regulations (1995) is that workers can receive a dose > 1 mSv a^{-1}. The Radiation Management Plan needs to identify a critical group, and sources of exposure and exposure pathways for both workers and the critical group. Justification of the equipment and facilities, institutional controls, training and monitoring, prior to and during operation, are also required. However, the level of detail should be commensurate with the potential radiological exposure and the expected difficulty in controlling it. Mineral stockpile management must also be addressed in a Radiation Management Plan since the radiation levels near the stockpile may be elevated and saltation can lead to material redistribution. Simple precautions can often reduce the associated risks (Department of Mining and Petroleum, 2010).

The depth and level of detail of the Radioactive Waste Management Plan should also reflect the amount and activity of the wastes, as well as the degree of processing, as this can affect the leachability of the radionuclides present. Therefore this information should be provided along with a description of the intended waste management facilities, the host environment and rehabilitation of the site. Finally, the expected emissions and long term monitoring programme should be addressed.

Tailings are often disposed of in excavated mine sites and Western Australia encourages the dilution of low level radioactive wastes with non-active wastes in to allow unrestricted future use of the site (Department of Mines and Petroleum, 2010). When this is carried out, the dilution must be sufficient for the mixed material not to be classified as radioactive (1 Bq g^{-1} ^{232}Th and/or ^{238}U). It is also only considered suitable for radioactive wastes generated prior to any chemical treatment that breaks the secular equilibrium. Dilution of contaminants is also recommended to allow the use of mine wastes in other industries, such as road building. The process for clearing materials for reuse is described in the NORM guidelines (Department of Mines and Petroleum, 2010). Western Australia also allows potentially valuable tailings to be stored in tailings dams for future use if adequate safeguards are in place (Department of Mines and Petroleum, 2010).

The attitude to NORM residues is changing in general (IAEA, 2013) and the recycling of NORM residues or their use as by-products are increasingly encouraged. This results from sustainability considerations and the realisation that minimsation of NORM wastes for disposal is needed ”in order to make their disposal manageable” (IAEA, 2013) and to lower costs. Some countries, such as the Netherlands, have made specific provisions in their national regulations for NORM residue recycling and reuse (IAEA, 2013). This is consistent with the IAEA’s fundamental safety principle that “the generation of radioactive waste must be kept to the minimum practicable level by means of appropriate design measures and procedures, such as the recycling and reuse of material” (IAEA 2006). Dilution of NORM residues is becoming acceptable in this context and it may also be acceptable to disperse some wastes that are close to the clearance level into the surrounding environment (e.g. land spreading).

The need to manage wastes from the remediation of NORM-contaminated sites has been seen to drive regulatory and policy developments in Brazil (Section 3.1.2). Other NORM remediation projects also show the importance of clear policies and disposal options. In Olen, Belgium, wastes arising from a radium extraction process were essentially dumped on two sites from 1922 till 1969, and the banks of a nearby river and some streets of the surrounding town also became contaminated. Part of the contamination has been remediated, but the dumpsites still require remediation. According to Belgian law, all radioactive waste must be managed by the public body NIRAS/ONDRAF, although the operator of the site is responsible for funding the work. The operator is currently waiting for the public body to develop a strategy for the management of long-lived NORM-waste. In Port Hope, Canada, approximately 1.2 million cubic metres of low-level radioactive waste from a uranium and radium refinery will be transferred to an engineered, above ground mound. This initiative follows a legal agreement between the Government of Canada and the local municipalities, federal funding and the approval of amendments to the site licence. Major remediation projects have also been initiated at former uranium mining sites, e.g. the Wismuth site in south-eastern Germany.

6.7. Mining and processing techniques

The principles of the Mining Waste Directive (2006/21/EC) and the BREF document on the management of tailings and waste-rock in mining activities (EC, 2009) are reflected in some modern international practice. The recently licensed processes at Mountain Pass, USA, involve the dewatering of tailings and pumping the resultant paste to an onsite, stable containment mound (US EPA, 2012a). It has been estimated that this will eliminate the need for 120 acres of evaporation ponds. The Industrial Emissions Directive (2010/75/EU) is also consistent with some developments in the USA. For example, 90 % of the wastewater generated at the new plant at Mountain Pass will be treated using reverse osmosis and reused. The RO reject will be further treated to produce value-added products that can be reused in the process or sold. Heavy metals that concentrate in the RO reject will be precipitated out of solution and removed using nanofiltration. The brine from this process will be dried on-site using evaporation ponds, prior to final disposal (US EPA, 2012a).

Thorium waste will be produced along with rare earths mined from the proposed operations at Pea Ridge, and the previous owners intended to construct a regional thorium stockpile with the rare earth refinery. The US Environmental Protection Agency (2012a) suggests that a thorium storage facility might help address environmental liability concerns in the production of rare earths. Thorium would be stockpiled in anticipation of using it as nuclear fuel.

The Western Australian Norm Guidelines (Department of Mines and Petroleum, 2010) encourage the use of the “best practicable technology” to reduce radiological risks, and remind us that optimisation is most effective and efficient at the design stage. A drive for technological improvements that benefit the industry, enhance yields and lower environmental impacts is also good practice, and the EURARE project is an example of this in Europe. Last but not least, awareness and simple measures often help improve radiological exposure situations, for example radiation doses to workers at Bayan Obo, China, have been improved by better ventilation and dust control equipment (IAEA, 2011).

7. Conclusions: Does EU legislation support the development of a sustainable REE industry?

Regulation of the mining industry is well established in Europe, and compares favourably with international standards. Furthermore, the BREF document for the management of tailings and waste rock (EC, 2009) promotes good practice. Since the main environmental and health and safety implications of REE mining are common to those of the non-ferrous metal mining industry, the legislation for a European REE mining industry is largely in place. However, since many aspects of mining are regulated through general environmental legislation, there are some issues that are not addressed directly. These include mine site management, which results in a lack of centralised control and affects the requirements for important potentially-polluting phases such as idle periods.

The regulation of NORM has also recently been improved through BSS (2013/59/EURATOM), and this meets or exceeds the requirements of IAEA BSS (2014). However, the BREF document for the management of tailings and waste rock (EC, 2009) does not address radioactive hazards and should therefore be extended to encompass the best available techniques for minimizing exposure to radiation and safe long term containment of the radionuclides. The Australian guidance documents (Department of Mines and Petroleum, 2011; EPA South Australia, 2010) and IAEA (2011) are good references for this.

The REE processing industry is also well served by existing industrial emission, waste management and environmental protection legislation. There is however a need to extend the BREF document on best available techniques in the non ferrous metals industries (EC, 2001) to include REE processes and, as for mining, address the best available techniques for minimizing radioactive hazards in the workplace and in waste management. Best available techniques for NORM waste disposal could build upon existing experience, for example in Norway and the UK. Additionally, individual member states can benefit by developing more prescriptive guidelines, limits or processes to meet the specific needs of their industries, as seen in Norway, UK and Australian territories.

With the development of the REE industry, there is a need to assess whether the environmental quality standards in place encompass and protect the environment against the main associated hazards. Additionally, the discussion of funding for the remediation of abandoned sites is applicable to the REE industry, thus the industry should be represented in the decision making process.

In conclusion, the existing EU legislation does support the development of a sustainable REE industry, but this could be improved further by an evaluation of the environmental quality standards in light of the REE industry, the inclusion of the REE industry in the decision-making process with regard to a remediation fund, and the development of the relevant BREF documents to include the REE industry and NORM.

8. List of acronyms and abbreviations

ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
BREF	Best Available Techniques Reference Document
BSS	Basic Safety Standards
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act (USA)
EIA	Environmental impact assessment
EPA	Environmental Protection Agency
EU	European Union
EURARE	EU Framework 7 project: Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits
ICRP	International Commission on Radiological Protection
IREL	Indian Rare Earths Limited
IAEA	International Atomic Energy Agency
LAMP	Lynas Advanced Materials Plant, Malaysia
MEP	Ministry of Environmental Protection, China
MIIT	Ministry of Industry and Information Technology of China
NORM	Naturally Occurring Radioactive Materials
REE	Rare Earth Element
RP	Radiation protection
UN	United Nations
USAM	Santo Amaro Mill, Brazil
USIN	Interlagos Mill, Brazil

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Appendix A. Summary of legislation in Russia

A list of relevant Russian mining and environmental legislation is found in Table A.

Federal and regional regulation

In accordance with the constitution of the Russian Federation, environmental protection legislation is enacted at both federal and regional levels (Josefson, 2012).

The main federal laws regulating environmental protection are Federal Law No. 7-FZ, "On Environmental Protection," dated 10 January 2001 (the "Environmental Protection Law"), and Federal Law No. 174-FZ, "On Environmental Expert Review," dated 23 November 1995 (the "Environmental Expert Review Law") (Josefson, 2012). (See also Table 1).

To produce natural resources, companies must obtain a number of licenses and permits including a subsoil license, a mining allotment, land use permits, operating licenses and a favourable environmental assessment (Morozova 2008).

International regulation

Russia is a party to most of the major international conventions and treaties in the area of environmental protection: Convention on Biological Diversity (1983, Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1989) and Convention on the Transboundary Effects of Industrial Accidents (1991) among others.

According to the Russian constitution, if the provisions of any environmental regulation established by an international convention or treaty and/or those established by the Russian federal or regional laws contradict, the provisions of the international convention or treaty prevail (Josefson, 2012).

Legislation of radioactivity

The Federal law "On Radiation Safety of Population" is the basis of a new (non-limit) concept of the cumulative effective radiation exposure dose received over the life of a person. The requirements of national radiation safety standards (NRB-99, OSPORB-99 and SPORO-2002) are further elaborated by 60 regulatory documents and 128 implementation guidelines (Sneve and Roudak 2013).

Table A. The legal framework of the natural resources industry of the Russian Federation, relevant to the REE industry.

Legislation	*Title*	*Relevance*
Related to activities with mining of minerals (the natural resources industry of the Russian Federation)		
Subsoil Law, No. 2395-I (Feb. 21, 1992), restated as Federal Law "On Subsoil," No. 27-FZ (Mar. 3, 1995)	Federal Law On Subsoil	Obligations under a Subsoil License among others: • To keep environmental contamination within specified limits, and • Certain social obligations, such as paying compensation to local indigenous groups in respective area and providing other types of support to the local communities.
Environmental protection regulations		
Federal Law No. 7-FZ dated 10 .2001	On Environmental Protection	• Sets out the fundamental principles of Russian environmental regulation, • Provides an overall framework for environmental management, and • Imposes general environmental protection requirements related to the construction and operation of various facilities that may be harmful to the environment. • Requires the performance of an environmental impact assessment (EIA) • Requires State Environmental Expert Review
Federal Law No. 174-FZ	On Environmental Expert Review	• EIA required • SEER required
The Codes of the Russian Federation	Civil Code Land Code Water Code Forest Code Tax Code Code on Administrative Violations Criminal Code	
Supreme Council Regulations on the Procedure of Enactment of the Provisions on the Procedure of Licensing of the Subsoil Use of 1992	"Subsoil Use Licensing Regulations"	
Related to radioactivity		
Federal Law No. 3-FZ dated 09.01.1996	"On Radiation Safety of Population"	[Sneve and Roudak 2013] The Federal Law defines the radiation safety of the population. The law establishes radiation-safety standards (radiation dose limits): • For the population, the average annual effective dose is 0.001 Sv or 0.07 Sv over the lifetime (70 years) • The annual effective dose for a particular year may be larger, provided that the average value over any five consecutive years does not exceed 0.001 Sv

		• For personnel, the average annual effective dose is 0.02 Sv or 1 Sv over the working life (50 years) • The annual effective dose for a particular year may be up to 0.05 Sv, provided that the average value over any five consecutive years does not exceed 0.02 Sv.
«Radiation Safety Standards» (RSS-99)		
Related occupational health issues (Skandfer et al. 2012)		
Federal sanitary norm	Guide on Hygienic Assessment of Factors of Working Environment and Work Load. Criteria and Classification of Working Conditions, Guide P 2.2.2006	
Regional methodical medical recommendations	Methodical recommendations: Organization of pre- and periodic examinations of workers exposed to dangerous and harmful industrial factors. Methodical recommendations for treatment- and prophylactic institutions, state sanitary-epidemiological supervision centers and departments of labour protection and safety of the Murmansk region enterprises	

Appendix B: Summary of legislation in the USA

The USA has both state and federal legislation, and the main, relevant federal legislation is summarised in Table B. The original acts have been amended over time to improve standards.

Table B The legal framework of the natural resources industry of the USA, relevant to the REE industry

Legislation	*Relevance*
Related to radioactivity	
U.S. EPA Ionizing Radiation Protection Program Regulations	Has sub parts covering: Rn emissions from operating mill tailings; mining of U, Rn and V; health and environmental protection standards for U and Th mill tailings, and ; Rn emissions from U mill tailings.
Related to chemicals and hazardous components	
Toxic Substance Control Act (1976)	Requires regulation of chemicals that present risk to health or environment. A revision is currently under consideration to clarify and strengthen the legislation.
Related to waste management and emissions	
Solid Waste Disposal Act (1976)	Regulates the generation, storage and disposal of hazardous waste and manages solid, non-hazardous waste (states).
Resource Conservation and Recovery Act (1976)	Protects human health and the natural environment from waste disposal. The Bevill amendment excludes wastes that are "uniquely associated" with mining and processing from regulation as hazardous wastes, and these are instead treated as non hazardous solid wastes
Environmental protection regulations	
Comprehensive Environmental Response, Compensation and Liability Act (1980)	Requires hazardous substance releases to be reported and an inventory of the chemical handled. Introduces the polluter pays principle and assigns liability for contamination. Also provides a fund for the clean up of abandoned sites and short term emergencies
Surface Mining and Control Act (1977)	Relevant to the operational, idle and closure/rehabilitation periods.
Clean Water Act (1972)	National Pollutant Discharge Elimination System permit program (1972). Basis for water quality standards (as per Code of Federal Regulations: Title 40 Protection of the Environment; Chapter I Environmental Protection Agency (continued) Sub chapter D - Water Programs)
Safe Drinking Water Act (1974)	Groundwater protection
Clean Air Act (1963)	Sets air quality standards
National Environmental Policy Act (1970)	Requires an interdisciplinary approach to environmental decision making through Environmental Impact Statements. Applies to federal government agencies and any project that involves federal funding, work performed by the federal government or permits issues by a federal agency.
Federal Land Policy and Management Act (1976)	Prevents undue and unnecessary degradation of federal lands.
Endangered Species Act (1973)	Lists threatened plants and animals; protection plans mandated.
Migratory Bird Treaty Act (1918)	Protects nearly all bird species
Work place regulations	

Occupational safety and Health Act (1970)	Health and safety requirements in the workplace
Mine Safety & Health Administration (MSHA) US Department of Labor Regulations (1977) (Mine Safety and Health Act of 1977)	Health and safety regulations for underground mines
Mine Improvement and New Emergency Response Act (2006)	Amends the MSHA (1977) to improve health and safety

Appendix C: Summary of legislation in Western Australia.

Australia has both federal and territorial legislation. Figure C shows the legislation controlling each stage of the development and closure of a uranium mine site in Western Australia, the location of Mount Weld REE mine. The same legislation applied to mine sites where workers may receive a dose > 1 mSv a^{-1}. Other acts that may have relevance, but are not listed in Figure C, are: Soil and land conservation act (1945); Conservation and land management act (1984); Land administration act (1997), and; the Native title act (1993) (Department of Mines and Petroleum, 2010, Part 4-2).

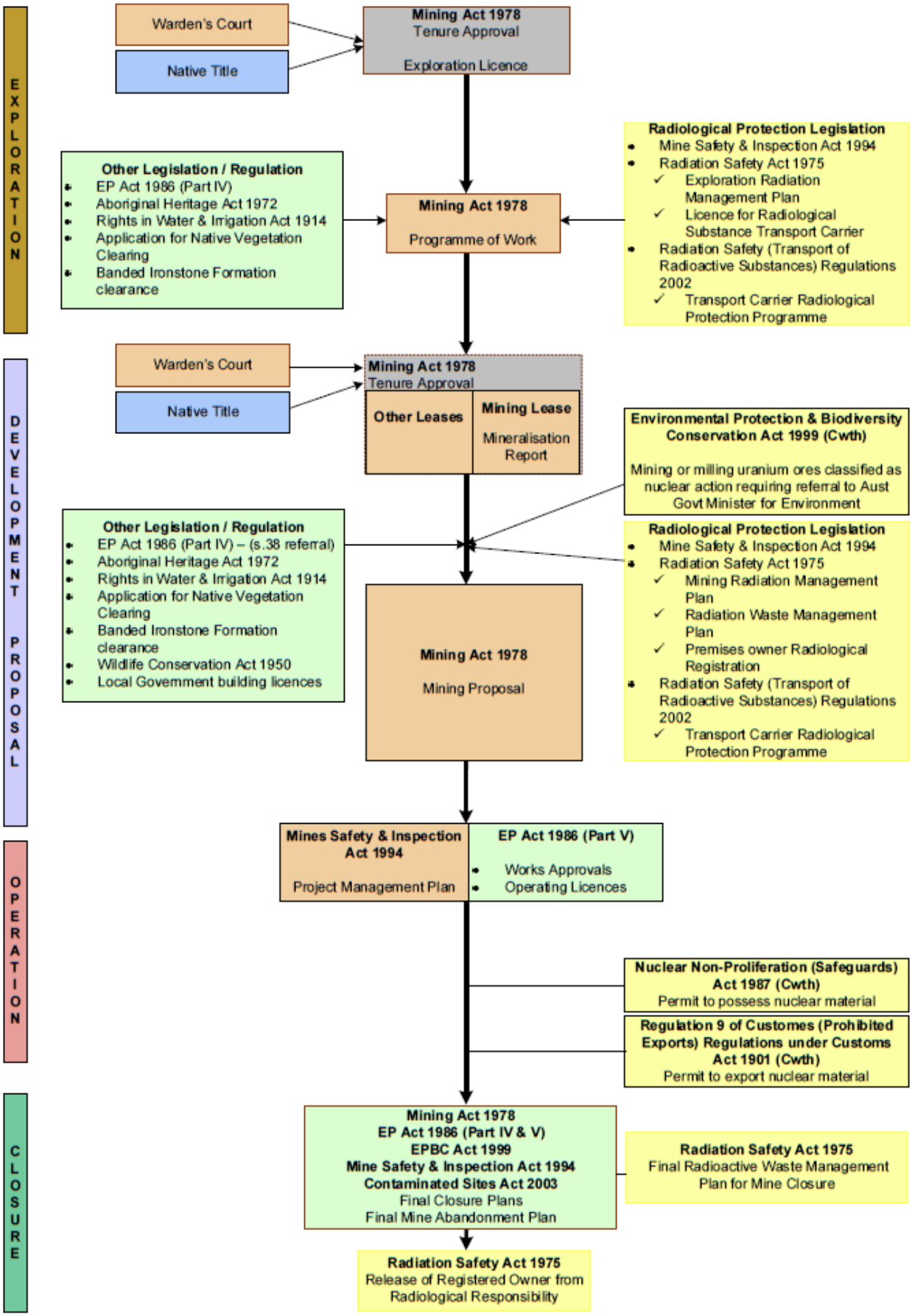

Figure C. Legislation relevant to uranium mining in Western Australia (Department of Mines and Petroleum, 2010)