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Description and critical environmental evaluation of the REE refining plant LAMP near Kuantan/Malaysia

Radiological and non-radiological environmental consequences of the plant's operation and its wastes

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Prepared on behalf of

NGO "Save Malaysia, Stop Lynas" (SMSL), Kuantan/Malaysia

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1 Introduction

Lynas Corporation, an Australian company with its Malaysian subsidiary Lynas (M) Sdn. Bhd., has constructed a facility in Malaysia to separate and refine several rare earth elements (REE) from a concentrated raw material that is rich in these metals. The original ore stems from its Mt. Weld mine in Western Australia, the first concentration step is performed near the mine. The concentrate shall then be exported, treated and refined in the Lynas Advanced Material Production (LAMP) facility in Malaysia. The products are to be sold on the global market. The wastes from the process are to be disposed of in a disposal facility in Malaysia.

A residents group, the non-governmental Organization (NGO) “Save Malaysia! Stop Lynas!” (SMSL) and several other groups oppose the import of these materials and the facility. SMSL’s main concerns addressed by the work of Oeko-Institute e.V. are:

1. The concentrate, to be imported from Australia, has radioactive thorium and uranium as by-products (Naturally Occurring Radioactive Material, NORM), together with their successors in the decay chains. Their concentration is even technically enhanced during the concentration and refining process (technologically enhanced NORM, TENORM). The TENORM wastes remaining from the separation of the REEs are to be disposed of in a designed disposal facility (for which the site and the design still has to be determined by the operator) and so remain completely in Malaysia. The NGO doubts that the safety of the temporary and the final disposal facility can be guaranteed. Lynas has yet to find a site for the permanent storage facility for the radioactive waste. The risk of contamination and radiation exposure to the local population and the environment needs to be assessed and evaluated independently.
2. The refining process is done in several steps, where large amounts of chemicals will be used. They have to be contained, treated and recycled or emitted. The NGO argues that the filtration or treatment methods proposed by Lynas may not be effective since law enforcement in Malaysia is seen as lax and most plants seldom pay much attention to their proper function and maintenance. Staff capacity in Malaysia is limited and appreciation of proper occupational health and safety procedures is often absent. In the event of the filtration and/treatment system failing to work effectively, emissions of the facility via air and water pathways could cause harm to people and the local environment. SMSL’s view is that the operator has constructed the plant in an unsuitable location and has not applied best available technologies to control, reduce and limit those emissions.
3. The plant is located in an ecologically sensitive area on a cleared mangrove peatland with a very high water table and only 3.5 km from the South China

Sea. The plant will discharge its treated effluent into a local river, the Balok River, which sustains an important mangrove habitat – the Balok Mangrove Area. The Balok River flows into the South China Sea. The Balok River and the South China Sea are crucial eco-systems for local fishing industry. The coastal area near the plant is Malaysia's coastal and marine tourism hotspot and a conservation area for a highly endangered species. The emissions from the plant need to be evaluated in respect to the consequences for this sensitive ecosystem.

4. The control, reduction and limitation of hazards associated with the operator's activities require a strong and strict regulatory control and monitoring of those activities. The public trust in the regulatory authority's ability to perform these tasks in an adequate manner, in respect to the nature and extent of the hazards, is almost nonexistent and it will take many real-life best-practice models over a long period of time to gain any trust from the public. So, as far as possible, the process is to be evaluated.

In addition, the following aspects are considered in the work on these issues, because they influence the NGO's view of the problems:

- Malaysia has had a poor experience with a much smaller (one-tenth the capacity of the Lynas facility) rare earth refinery plant in the town of Bukit Merah, Perak. Until today, toxic waste dumped from this closed plant has yet to be cleaned up. Little has changed since then as far as environmental governance is concerned in Malaysia.
http://www.malaysiatimes.my/en/2012/02/18/chronology-of-events-in-the-bukit-merah-asian-rare-earth-development/
- Within 30 km from the Lynas plant live around 700,000 people, the closest residential estate being only about 3 km from the plant. The seafood and tourism industries are the main employers for the local people.
- The NGO is also concerned that Lynas' proposed recycling of the non-radioactive waste may not be safe. To date, Lynas and the Malaysian government have yet to disclose in detail what kind of commercial by-products will be recycled from Lynas' non-radioactive waste streams and how they will be used.
- The NGO is of the opinion that Lynas does not have any experience in the design, construction, operation, maintenance and waste disposal from rare earth refining.
- The NGO argues that the plant was rushed through in its construction, hiring and firing a number of external contractors and sub-contractors, losing its institutional memory along the way.
- The construction of the plant was rushed through especially when it was known that China has imposed a quota to restrict its rare earth export. Lynas has pro-

moted itself to be the world's first largest producer outside of China which resulted in a massive rise in its share value. The rush to be the world's first and biggest has, in SMSL's opinion, compromised the quality of plant construction adding to the risk to workers, the environment and the local population.

- The operator's activities require a strong and strict regulatory control and monitoring. The NGO argues that control, reduction and limitations of hazards are not fulfilled by the state regulation and authorities because of a lack of political will, governance weaknesses and institutional capacity limitation. Environmental law enforcement in Malaysia leaves much to be desired as evidenced in many ways. The levels and standards required to safely manage the hazards and risks are unlikely to be met by the relevant authorities. The regulatory agencies do not have the necessary professional competence and tradition to guarantee for a strict control regime. The public trust in their ability to perform these tasks in an adequate manner, in respect to the nature and extent of the hazards, is almost nonexistent and it will take many real-life best-practice models over a long period of time to gain any trust from the public.

The environmental NGO SMSL in Malaysia requested Oeko-Institute e.V. to perform an independent environmental evaluation on radioactive waste management and emission issues of the Lynas facility near Kuantan/Malaysia. Oeko-Institute discussed this request thoroughly, agreed to place an offer for these activities and performed the tasks described below on behalf of SMSL.

The tasks of Oeko-Institute were therefore:

- to independently check the plans of Lynas, as to whether the applied technical standards meet "best available technology" criteria and sustainability criteria (e.g. not posing undue risks to the public, the environment and to future generations),
- to make clear which risks and consequences the possible failure of control and oversight might have,
- to develop recommendations on how to achieve the necessary control and oversight to limit the risks and to reduce the consequences.

This report was prepared after visiting the site and its neighborhood. The author wishes to express his thank for the reliable help of SMSL in getting documents and background information together, for the numerous open talks with Malaysians familiar with the issue and all the friendly assistance to the European expert in order to better understand local perceptions, fears and expectations.

Understanding the perceptions of SMSL did influence, but did not determine the expert work performed here or its results. The work was done completely independently, as is tradition at the Oeko-Institute and is required and guaranteed by its statute.

The work that had to be done here was exceptionally complex. Usually an Environmental Impact **Statement (EIS)** report, prepared on behalf of the operating company, is reviewed by the responsible regulating agency that evaluates the environmental consequences based on its own (or its consultant's) expertise and finally publishes the results of its review in an Environmental Impact **Assessment (EIA)** report. Not so here. The EIS is directly called an EIA, and a critical review was either not prepared or has not been published. So when working with the document, part of this work was typical "regulator's work" (checking plausibility, reviewing calculations, etc.). Thus the typical approach of expert work for a Non-Governmental Organization, namely to identify selected issues that the regulator has overseen, had to be replaced here by the performance of an extensive work package.

Photos and figures in the report for which no reference is cited are from the author.

A number of persons have, in part or completely, reviewed this report. The author wishes to thank these persons for their work and their valuable contributions.

The report is structured as follows:

- Chapter 2 provides some basic information on the plant, the process, the chemicals used and their adverse environmental properties.
- Chapter 3 evaluates radioactive and non-radioactive emissions of the plant to air and water as well as the hazards arising from the plant.
- Chapter 4 discusses and evaluates the waste issues associated with this production at the plant.
- Chapter 5 summarizes the findings of the report.

2 Basics and background of the plant

2.1 The plant's location

The Lynas Advanced Materials Plant (LAMP) is located near the city of Kuantan in Malaysia on the east coast (see Fig. 2.1).

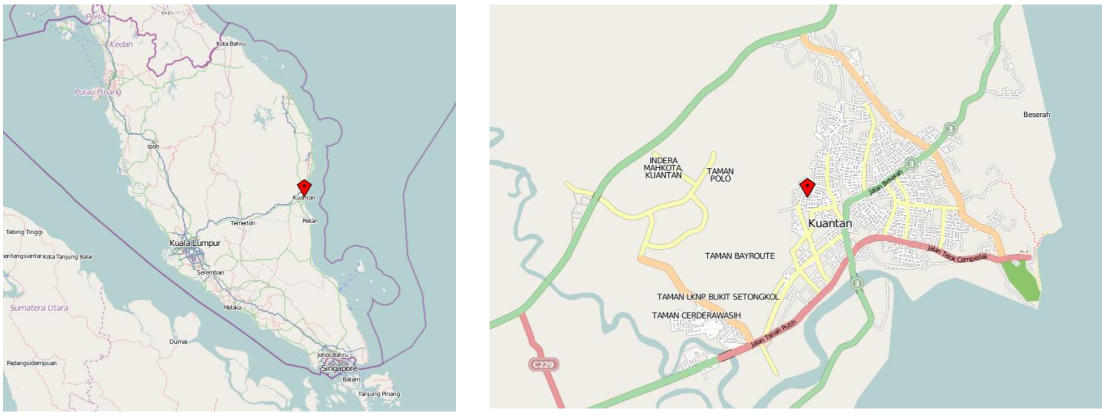


Fig. 2.1: Location of Kuantan in Malaysia (©OpenStreetMap contributors)

It is located in an industrial area in the southeast of Kuantan called Gebeng Industrial Estate (see Fig. 2.2).

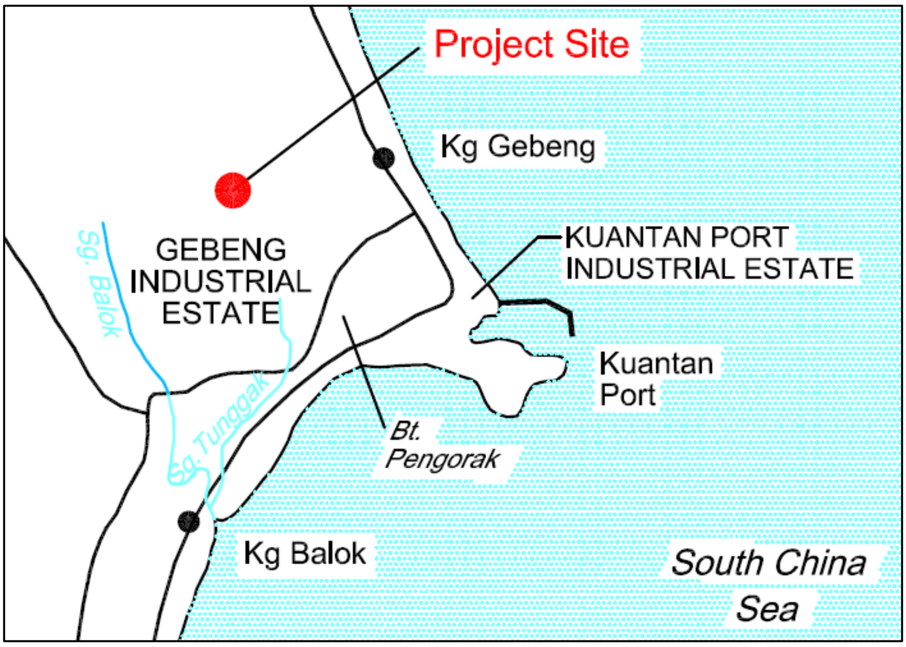


Fig. 2.2: The plant's location, excerpted from /Environ 2008/

The Gebeng industrial area is a cleared forest area on peatland, where large and small industrial estates (petrochemical industry, etc.) have been created, usually by filling up the peat surface with earth and other cover materials. Fig. 2.3 shows the

Lynas plant area on the left, the original mangrove forest to the right, and the rising fill layer in between.

Fig. 2.3: Left: Cleared and filled industrial Lynas site area, right: Forest area

Fig. 2.4 shows the plant's extension under construction, with a water pond in front.

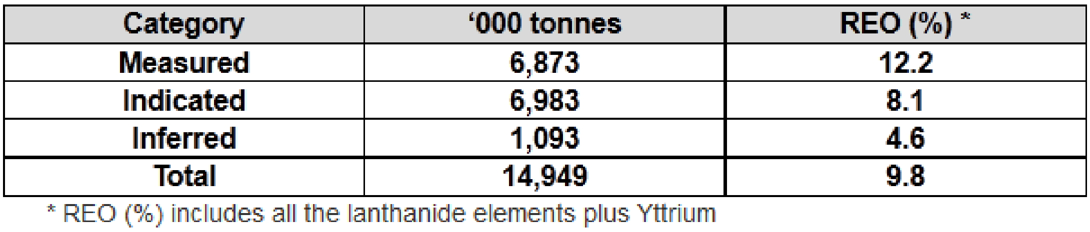
Fig. 2.4: Lynas plant seen from the west boundary with extension under construction

2.2 The plant's internal functioning

The plant uses an ore concentrate from Mt. Weld in Australia as input material to produce several rare earth element components to be finally marketed.

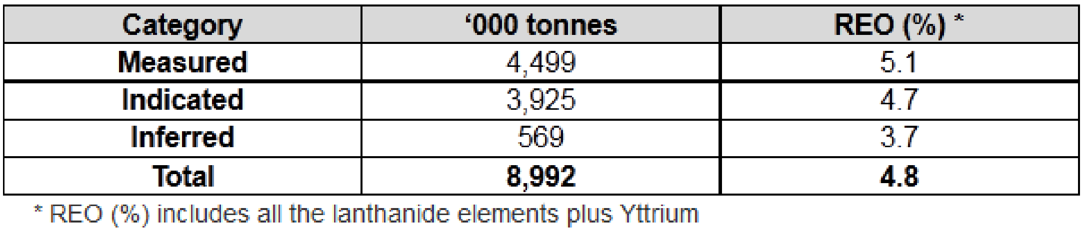
The eare earth oxide (REO) content of the original ore is listed in Table 2.1.

Table 2.1: Mineral resource classification of the Mt.Weld central lanthanide and the Duncan deposit (as rare earth oxide), from /Lynas 2012/



Category	'000 tonnes	REO (%) *
Measured	**6,873**	**12.2**
Indicated	**6,983**	**8.1**
Inferred	**1,093**	**4.6**
Total	**14,949**	**9.8**

* REO (%) includes all the lanthanide elements plus Yttrium



Category	'000 tonnes	REO (%) *
Measured	4,499	5.1
Indicated	3,925	4.7
Inferred	569	3.7
Total	**8,992**	**4.8**

* REO (%) includes all the lanthanide elements plus Yttrium

The ore is concentrated in a beneficiation step at the mine site in Australia, yielding an ore concentration by a factor of 3 to 4 higher than in the ore. This ore concentrate is planned to be shipped to Malaysia and there to be further processed in the LAMP plant.

The LAMP plant in Malaysia consists of the following stages:

1. Cracking stage: In this first stage the ore concentrate is mixed with concentrated sulfuric acid, the slurry is fed to a rotary kiln and heated to 350 - 450 °C, for which natural gas is consumed. Temperatures are well above the boiling point of the sulfuric acid (330 °C) to dissolve the rare earth elements present in the concentrate, thereby also dissolving other by-products in the ore (e.g. thorium and uranium). The sulfuric acid vapor is cooled and fed back into the process. Remaining acid vapor and reduced sulfur dioxide in the gas stream are treated in the flue gas desulfurization (FGD) facility, neutralized with lime ($CaCO_3$) to form a mixture of gypsum (calcium sulfate) and calcium sulfite, leaving the process as waste, to be stored in a designated storage facility, the FGD-RSF. The offgas from the FGD is finally discharged over a stack.
2. Water leach and purification stage: The concentrated sulfuric acid solution with the dissolved materials is diluted with water and treated with magnesium oxide to reduce the pH of the solution. Dilution and pH-reduction results in the precipitation of several by-products. Insoluble ore concentrate components and precip-

itated by-products are filtered, washed and finally transported as a paste to a storage facility (Water leach purification residue storage facility, WLP-RSF).

3. Separation stage: The solution is then mixed with hydrochloric acid (HCl) and extracted in seven single extraction stages with organic chemicals to separate the different rare element chlorides and to remove impurities such as iron chloride from the extraction liquid.
4. Product finishing stage: The different extraction liquids are treated with sodium carbonate (LPCN chloride solution), neutralized with magnesium oxide (SEG and HRE chloride solution) and precipitated with sodium carbonate solution or precipitated with oxalic acid (Dd chloride), filtered and either marketed as such or followed by additional stages to yield marketable products and product qualities of
   - SEG/HRE[1] carbonate,
   - LCPN carbonate,
   - LC carbonate,
   - Lanthanum carbonate,
   - Cerium carbonate, and
   - Deodymium[2] oxide.

Detailed block diagrams of all these stages are available on Exhibit 2.3 of the PEIA /Environ 2008/.

2.3 The plant’s input, output and material balance

The following chapters provide basic information on the plant’s material balance and the internal processes that play a role for understanding environmental impacts from emissions and wastes.

2.3.1 The plant’s input and output materials

Fig. 2.5 lists all input and output materials of the LAMP plant.

Input materials are:

- Ore concentrate, to be imported from the Mt. Weld Mine in Australia,
- Water, either as raw water or as supernatant solution plus collected precipitation from the WLP storage pond,
- Natural gas for heating the kilns,

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[1] See the list of abbreviations in the attachment.

[2] Also called didymium (twin element).

- Concentrated sulfuric acid, to be delivered from the nearby production plant and used to digest the ore,
- Concentrated hydrochloric acid, to be used in the separation stages of the plant,
- Magnesium oxide, used to neutralize the sulfuric acid,
- Soda ash and lime to neutralize the hydrochloric acid,
- Oxalic acid for the purification of the products,
- Solvent and kerosene for separation and extraction.

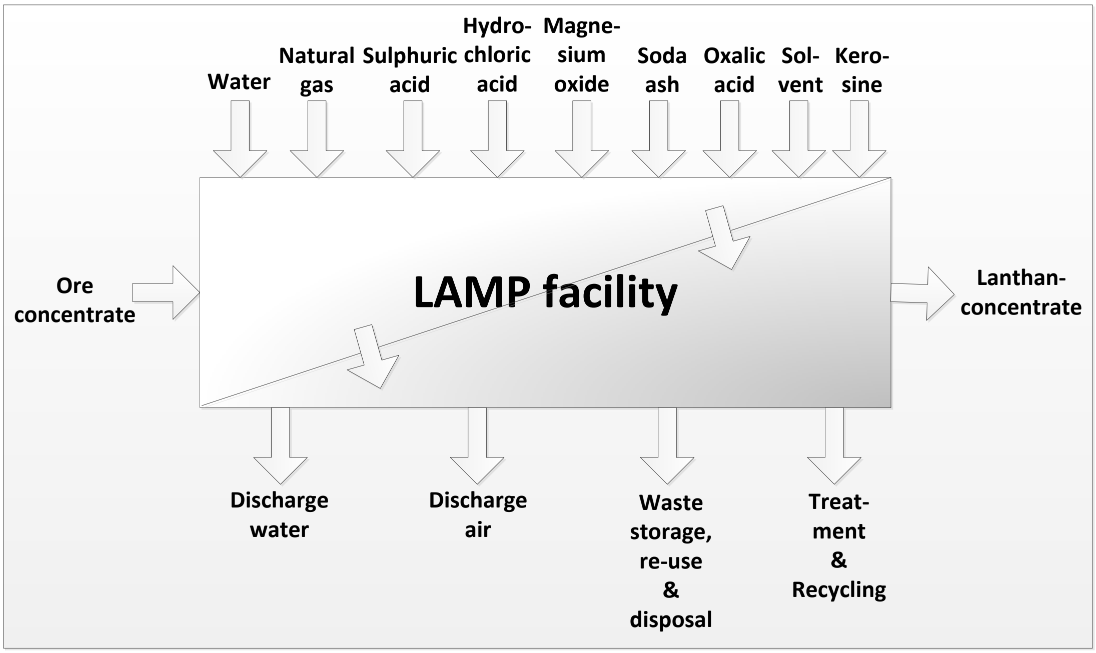


Fig. 2.5: The LAMP plant input and output materials

Output materials are:

- Diverse REE (lanthanum, cerium, praseodymium and neodymium, etc.) components as marketable products,
- Discharged wastewater following cleaning,
- Discharged offgas after cleaning,
- Several waste streams, to be stored and either re-used or disposed,
- Used chemicals, especially solvents and kerosene, to be treated, cleaned and recycled externally.

Not mentioned are minor amounts of additional chemicals used to finish the different products (e.g. barium chloride).

2.3.2 The plant's material balances

Table 2.2 lists the plant's material balance for all major inputs and outputs. Unknown amounts of material with some environmental relevance, for which no quantitative figures are given in accessible documents (e.g. for the by-product composition of the ore concentrate) or for which apparently faulty and inconsistent information is given (e.g. for the treated water discharge in Exhibit 2.2 of /Environ 2008/) were labeled with a "?".

The yearly amounts listed (column 5, "Flow" in tpa) were collected from various documents. The estimates for the whole lifetime of the facility were calculated from this yearly amount by multiplying with a factor of 19.5. All numbers in the table are rough figures with several percent uncertainties, so the digits beyond the leading two digits are uncertain and are rounded accordingly in column 6.

Table 2.2: Material balance estimate for the LAMP plant, yearly and overall total

Categ.	Material	Sub-category	Content	Flow, tpa*	Total, tons
Input	Ore Concentrate	Complete	-	65,000	1,270,000
		Thorium	0.16 wt-% ThO_2	104	2,030
		Uranium	0.0029 wt-% U_3O_8	1.885	37.000
		Other By-products	(unknown)	?	?
	Raw water	-	-	?	?
	Natural gas	-	-	42,912	837,000
	Sulfuric Acid	concentrated	98%	110,238	2,150,000
	Hydrochloric Acid	concentrated	36%(?)	146,776	2,860,000
	Magnesium Oxide	-	-	23,348	455,000
	Soda Ash	-	-	19,632	383,000
	Lime	-	-	52,226	1,020,000
	Oxalic Acid	-	-	8,924	174,000
	Solvent	-	-	780	15,200
	Kerosene	-	-	1,72	33,500
Output	Products	(Six products)	-	22,500	438,000
	Wastewater	Process water	-	?	?
		Supernatant NUF	-	?	?
		Supernatant FGD	-	?	?
		Surface water runoff	-	?	?
	Off gas	-	-	** 99,344	** 1,940,000
		Radon-220	MBq	*** 370,930	*** 7,230,000
	Waste	WLP waste	dry base	64,000	1,250,000
		FGD waste	dry base	55,800	1,090,000
		NUF waste	dry base	170,600	3,330,000
	Spent Chemicals	Solvent	-	780	15,200
		Kerosene	-	1,72	33,500

* Tons per year; ** Nm^3/a or Nm^3; *** MBq (without decay in the kiln and offgas treatment system)

The most relevant materials in terms of their mass are concentrated acids on the input side. Those concentrated acids have to be transported, stored and contained within the plant and have to be handled carefully. The associated hazards are discussed in chapter 3.5.

Their neutralization counterparts (such as lime or magnesium oxide) are also bulky input materials. On the output side, this leads to large amounts of salts with

- Sodium, magnesium and calcium as cations,
- Sulfate and chloride as anions.

Part of these generated salts leave the LAMP via waste streams (e.g. calcium sulfate, gypsum), some are discharged via the water path (e.g. magnesium and chloride). The environmental relevance of those discharges is evaluated in chapter 3.4.

Note that the radioactive radon-220 was calculated from the thorium content, not taking its decay into account. The detailed radiological evaluation is discussed in chapter 3.2.

Detailed descriptions, implications and environmental consequences of the three waste streams - WLP, FGD and NUF - are further discussed in chapter 3.5.

2.3.3 The plant's current status

The construction permit for the plant was issued in 2008. In January 2012, the plant was issued a Temporary Operating License (TOL). The purpose of this license is described as follows:

> *"Furthermore I also declare that the TOL granted to LYNAS is of a temporary and restricted status for the purpose of verifying the normal operating process of the LAMP project before being granted a class A license for full operations by AELB." /MOSTI 2012/*

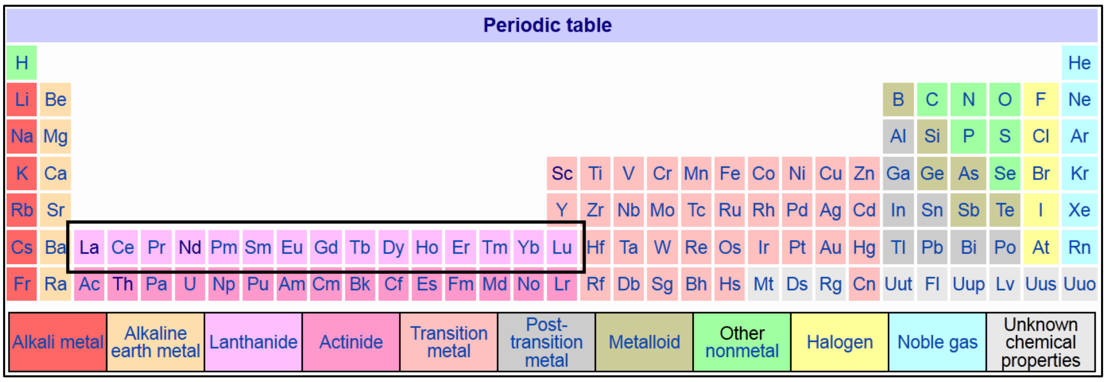
Exact definitions, the exact extent (e.g. in type and mass of input material), the verification criteria, etc., that the TOL is thought for, are not exactly known. Different sources (the license text, ministerial public announcements, operator's announcements, media reports, etc.) allow for different interpretations.

2.4 The production process and its non-radiological hazards

This chapter describes some basic facts about the raw material and the chemicals involved in the production process. These facts are referenced later in this report, when the hazards are described in more detail. The description here is thus very brief.

2.4.1 Rare earth elements

The rare earth elements (lanthanides) form a group of elements and range from lanthanum (La) to lutetium (Lu), as indicated in Fig. 2.6. Scandium (Sc) and yttrium (Y) are sometimes[3] added to that group because of their similar geological, chemical and biochemical behavior.



Periodic table

H																															He
Li	Be																									B	C	N	O	F	Ne
Na	Mg																									Al	Si	P	S	Cl	Ar
K	Ca															Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr															Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

Alkali metal	Alkaline earth metal	Lanthanide	Actinide	Transition metal	Post-transition metal	Metalloid	Other nonmetal	Halogen	Noble gas	Unknown chemical properties

Fig. 2.6: The rare earth elements in the periodic system of elements, modified after en.wikipedia.org

These elements are rather abundant in the earth's crust, but are only rarely found in concentrations where mining and milling is technically feasible in order to purify and produce pure oxides of a single element or a mixture of two or more of these elements and to market those.

Toxicity

Although they are rather abundant, /Paul 2011/ describes the threats of rare earth elements as follows:

> *"The threats to human health and the environment from radionuclides are well known, but the threats from rare earth elements are equally unknown. The movement of rare earth elements in the environment is generally lacking. The toxicology of rare earth elements to aquatic, human, and other terrestrial organisms is not well understood either. The toxicological effects would largely depend on the rare earth element compound and the dose of that compound."*

Biological effects and clinical findings such as those listed in /Bastarache 2012/, animal experiments with rats to determine LD_{50}[4] values /Bruce 1963/, research

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[3] E.g. IUPAC's, the physicist's and chemist's union, includes those two elements in their REE definition.

[4] LD_{50} determines the mass intake (e.g. as milligram per kg) that causes death to half of the test animals.

among persons that were affected by elevated REE uptake such as /Zhang 2000/ and compilations of toxicity studies in order to determine risk factors such as /TERA 1999/ show that the toxicity effects are manifold, and depend upon the chemical form and the application mode (chronic vs. single application, lung vs. ingestion, etc.).

The following can be concluded from this literature:

- As to current knowledge, the toxicity of REEs is low to medium and comparable to other metals.
- Currently no indications are given on cancerogenic and mutagenic effects.
- As there are known toxicological effects and as the knowledge on their distribution characteristics via water- and bio-pathways is limited, emissions of these metals to air and water shall be limited and carefully monitored.

2.4.2 Ore concentrate

Ores rich in rare earth elements always have by-products of other substances with adverse environmental properties. Among those can be metals and semi-metals such as aluminum, arsenic, cadmium, cobalt, copper, gold, iron, lead, manganese, silver and zinc. Anions include carbonate, phosphate and fluoride.

The content can vary within the different strati of the ore body, so when average contents are stated data on maxima and minima should be also stated.

In the beneficiation stage, that separates the mined ore from material with lower concentrations of REEs, the by-products typically are not removed or reduced, so that the resulting concentrations of by-products are even higher (in terms of mass-%) than in the mined ore.

2.4.3 Acids

As can be seen from the list of chemicals that are added to the ore concentrate during the process, large amounts of sulfuric acid and hydrochloric acid are used. These acids

- are highly corrosive, esp. hydrochloric acid, so that plant equipment has to be of a special design and material selection,
- are aggressive to human tissue, so that losses due to leakages, equipment failures, etc., have to be detected as early as possible and repair measures, recovery of acid, etc. has to be immediately at hand to prevent major accidents and their adverse consequences,
- cause serious damages to any biological material, if released via stacks or through leakages and can spread to the environment (e.g. as precipitated mist or as liquid loss to the groundwater).

Fortunately these adverse properties can be changed by neutralizing the acid and by dilution. Note that neutralization leads to salts, which are less environmentally aggressive but still have the potential to interfere with biological mechanisms and so, at least at higher concentrations, are not healthy.

As the applied acid requires neutralization within the process, neutralization chemicals such as lime (CaO) and magnesium oxide (MgO) are added to form somewhat soluble salts (e.g. gypsum $CaSO_4$) or readily soluble salts (e.g. calcium chloride $CaCl_2$).

2.4.4 Other chemicals

The rare earth extraction plant uses several other chemicals in smaller amounts. Among them are inorganic chemicals, such as barium chloride, as well as organic chemicals, such as iso-octylamine or kerosene in the extraction stage.

3 Radioactive and non-radioactive emissions of the LAMP plant

One main focus of this study is to provide an independent evaluation of emissions from the LAMP plant during normal operations and to determine whether

- avoiding and minimizing those emissions is to a quality that is state-of-the-art, and
- if for the unavoided emissions their adverse environmental consequences were described and evaluated in the PEIA in a correct way.

Two different kinds of emissions have to be looked at separately: radioactive and non-radioactive emissions. This is because their nature and consequences are too different to be discussed together.

This chapter first provides basic information on radioactive ore constituents (in chapter 3.1) and then evaluates radioactive discharges from LAMP (chapter 3.2).

The following chapters discuss the basic characteristics of radioactive hazardous ore constituents and the radioactive emissions from the plant (chapter 3.1 and 3.2) and evaluate their environmental consequences of the emission via the air (chapter 3.3) and water pathways (chapter 3.4).

3.1 Basic characteristics of radioactive ore constituents

3.1.1 Thorium content of the ore

The ore concentrate, to be imported from Lynas's mine facility at Mt. Weld (Australia) contains roughly 1,600 ppm of thorium (0.16 weight-% as ThO_2) and 29 ppm of uranium oxide (0.0029 weight-% as U_3O_8) as by-products. This content of thorium is

- very high compared to the lowest bandwidth of uranium content of commercially mined uranium ores today (> 0.03% U, e.g. at Rössing/Namibia), while the uranium content of the ore concentrate is lower by a factor of 10 compared to those uranium ores,
- considerably higher than the thorium content in many other REE ores, e.g. by a factor of roughly 3 larger than at Mountain Pass (USA), but by a factor of roughly 10 less than in (historically or currently mined) monazites.

Even though such more general comparisons are not very enlightening, the elevated thorium content in such ore requires specific attention in several areas:

- Handling, transport, chemical treatment, emissions and wastes must all consider the radiation characteristics of the materials. Therefore the protection of workers, the public and the environment from the adverse consequences of thorium and its decay products is relevant.

- The longevity of the associated hazards means that responsibility must be taken for the limitation and control of the hazards, that arise once the ore has been removed from its natural geologic location with its undisturbed isolation characteristics, its stability being further disturbed by mining, milling and chemical treatment of the material.

3.1.2 Thorium decay characteristics

In order to limit and control hazards it is necessary to understand the radiation characteristics of the thorium in the ore and to have some basic knowledge about thorium.

Natural thorium can be found enriched in several minerals, where it is chemically bound e.g. to phosphate ions to form extremely water-insoluble minerals. It consists of the isotope Th-232, that decays with a half-life time of roughly 14 billion years. Due to this long half-life time it can still be found in the earth's crust ("primordial"). The decay starts with the emission of an alpha-particle (Helium), the decay product is radium-228. As the decay product is not stable it decays with a half-life time of 5.75 years to Actinium-228, emitting an electron (Beta decay) and a gamma ray. This again decays to another instable product, thorium-228. In several further steps stable Lead-208 is reached. The complete decay chain and the associated decay modes are shown in Fig. 3.1 (simplified).

As all the half-life times below Th-232 are shorter, natural thorium is always found in close association with its complete decay chain, and any of those decay products have an activity (in Bq) or activity concentration (in Bq/g) equal to Th-232 (except Po-212 and Tl-208, which are build up as branches and add up to one). This is called secular equilibrium (sec) and means that for each decaying Th-232 atom exactly one atom of any nuclide in the decay chain decays in the same time period. As there are ten decay products in the chain (with Po-212 + Tl-208 = 1) the total activity concentration (TAC) of thorium is ten times larger than that of Th-232 alone. The very often used abbreviations Th-232+ or Th-232++ or Th-232(sec) all mean "thorium with its complete decay chain in equilibrium". "Equilibrium" means that in a certain time the same amount of each single nuclide (in atoms or mass units) is generated by decay of the predecessor as decays to the following nuclide(s) in the chain.

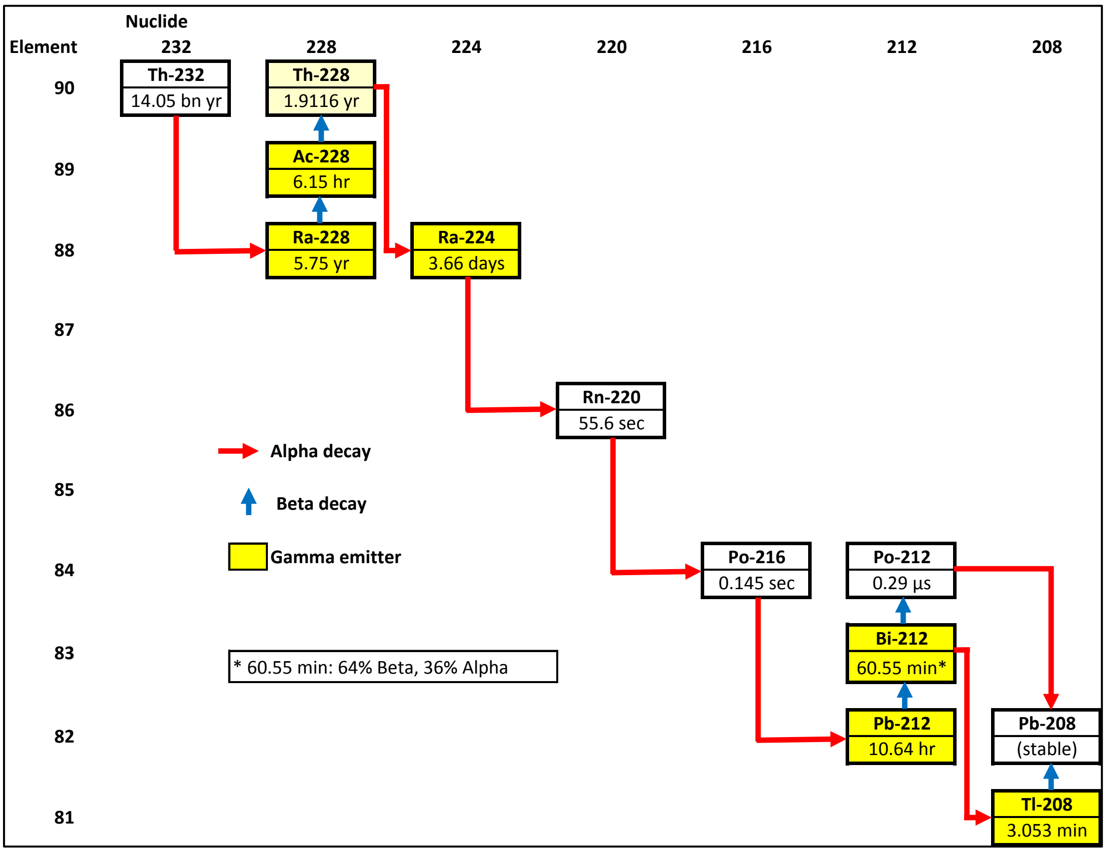


Fig. 3.1: The thorium decay chain (branches < 1% omitted)

Table 3.1 lists the activities and masses of all major decay chain nuclides in one ton of ore concentrate to be imported from Australia by Lynas Corp..

Table 3.1: Activities and masses of radionuclides in ore concentrate

Radio-nuclide	Halflife time	(per ton of RE concentrate)	
		Activity(Bq)	Mass/Dimension
Th-232	14.05 bn yr	5,710,000	1406 g
Ra-228	5.75 yr		566 ng
Ac-228	6.15 h		69.0 pg
Th-228	1.9116 yr		188 ng
Ra-224	3.66 days		0.97 ng
Rn-220	55.6 sec		167 fg
Po-216	0.145 sec		428 ag
Pb-212	10.64 hr		111 pg
Bi-212	60.55 min		10.5 pg

The following mass units mean:

- ng, Nanogram, 0.000,000,001 grams,

- pg, Picogram, 0.000,000,000,001 grams,
- fg, Femtogram, 0.000,000,000,000,001 grams,
- ag, Attogram, 0.000,000,000,000,000,001 grams.

As can be seen from the table, all nuclides decay with roughly 5.71 million decays per second (Bq) each, but the masses of the decay chain nuclides, build-up and decaying in each second, are extremely small (in all cases less than 1 µg/ton). That means that the chemical toxicity of the different elements in the decay chain do not play a relevant role, because their radio toxicity is much larger than their chemical toxicity (when inhaled or ingested).

3.1.3 Gamma doses and dose limitations

The gamma rays, emitted during the decay, can easily be detected. In the vicinity of the ore concentrate a gamma dose rate of 2 to 3 µSv/h can be measured, adding up to approx. 26 mSv/a if a person were to stay for a whole year (8,760 h/a) in this vicinity (see the following chapter on dose and risk). This dose would

- slightly exceed the adopted protection level for workers of 20 mSv/a,
- exceed accepted protection levels for the general public from the controlled emissions of nuclear installations of 1 mSv/a by a factor of 26,
- be by a factor of roughly 8 larger than average doses from natural sources (mainly caused by inhalation of natural radon-226 and its decay products), and
- be by a factor of 260 larger than 10 µSv/a, the accepted dose for practices where risks are considered well below any regulatory concern.

3.1.4 Dose and risk relationships

Table 3.2 gives an overview on these and a selection of internationally used dose limits and constraints and adds a rough estimate on the accepted health risks imposed by those dose limits. It has to be noted that the scheme is simplified because each regulation cited has additional conditions (e.g. life-time limitations for workers), so the selected examples are not complete and formally accurate (e.g. German emissions control law establishes separate limits for controlled emissions via the air and the water paths). The estimates are based on the Linear-No-Threshold concept (LNT, see Fig. 3.2 for an illustration of this concept) as recommended by the International Radiation Protection Commission (ICRP) and on a dose-risk-conversion factor of 1 in 18 per Sv ($5.6 \cdot 10^{-2}$/Sv$^{)}$. It should be noted that a large variety of conversion factors are used, so the resulting numbers are only rough estimates and are exact within an order of magnitude (1:10).

Table 3.2: Dose limits and constraints and estimated health risks

Area	**Regulation**	**Dose limit or Constraint mSv/a**	**Accepted Risk 1/a**	**Risk 1 in ... per year**
EU	Collective dose of all releases from regulatory control (per country)	1,000	$5.6 \cdot 10^{-2}$	18
ICRP for a single Year	Workers in the nuclear industry	50	$2.8 \cdot 10^{-3}$	360
ICRP over five consecutive years, Lynas, Germany (Cat.A)		20	$1.1 \cdot 10^{-3}$	900
Germany (Cat.B)		6	$3.3 \cdot 10^{-4}$	3,000
ICRP, EU	Controlled emissions from nuclear installations	1	$5.6 \cdot 10^{-5}$	18,000
D (0.3 via air plus 0.3 via water)		0.6	$3.3 \cdot 10^{-5}$	30,000
MY		0.3	$1.7 \cdot 10^{-5}$	60,000
BRC	Waste release from regulatory control	0.01	$5.6 \cdot 10^{-7}$	1,800,000

The table shows that accepted risks for workers are in the range of 1:360 to 1:3,000, for controlled emissions in the range of 1:18,000 to 1:60,000 and for wastes released to the public domain less than 1 in a million per year.

The dose-risk relationship used here assumes that there is a direct relationship between dose and associated health risks. This is an assumption because no scientific methods exist and can be applied to determine whether this assumption is true or not. This relationship is recommended for the use in radiation protection by the International Commission on Radiation Protection (ICRP). For a few chemicals that cause cancer, such as arsenic, chromium-VI, dioxin, similar dose-risk relations have been adopted.

In the LNT concept there is no lower limit at which health damages can be completely excluded. The minimization of doses even below the accepted limits is therefore necessary.

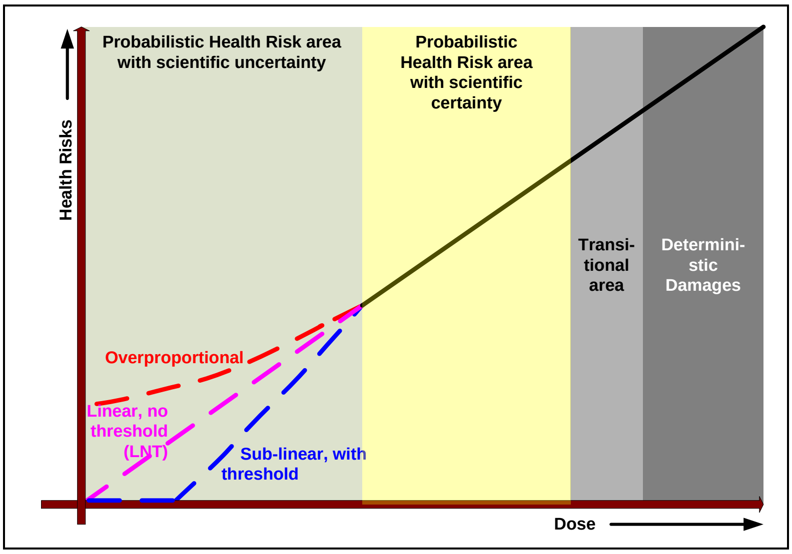


Fig. 3.2: Dose/risk relationships

The risk relationships used in this study provide a quantitative scale. As this is based on ICRP's dose-risk factor, it is not (over-)conservative but state-of-the-art in today's radiation protection calculations. Other criteria that are often used to evaluate risks or to communicate risks to laypersons, such as

- average concentrations of nuclides in earth in Malaysia,
- natural background radiation,
- concentrations in other ores or other facilities,
- radioactive waste classifications for other wastes or in other countries,
- etc.

are inappropriate to evaluate and communicate on risks. Risks are also associated with those natural or background sources, so these provide no "baseline" for "zero harm". As those natural risks can be reduced, e.g. by limiting radon levels in homes by selection of appropriate building materials and avoiding those with known elevated radium content, the risks from natural sources provide no fixed baseline on their acceptability. A quantitative risk remains a quantitative risk, be it natural or manmade.

So even below the accepted limits, the dose from gamma rays can (and should) be avoided during handling, treatment and disposal by means of

- limited access times where workers or people are exposed,
- keeping distances to the material,
- shielding (with metals such as lead, with water, with cover materials over disposal areas, etc.).

As thorium does not decay in relevant timespans, these protection measures have to be maintained for as long as possible once the thorium has been removed from its “naturally shielded” location in the earth, where it was mined from, and after altering its “geochemically mobility-protected setting in the geologic formation” in chemical processes.

3.1.5 Chemical alteration and scale enrichment

Chemical treatment of the ore concentrate can influence and alter the decay chain equilibrium in that under specific chemical conditions a separation of decay chain elements occurs. An initial crust or an encrustation (e.g. of radium sulfate) is accumulated on a surface, leading to even higher accumulation because the specific crystal structure of the initial crust attracts and absorbs particles of a similar structure (e.g. like in other crystal growth processes). If this happens e.g. for radium on the surface of a pipe, within a valve or on the filter cloth of a separator, the radium can accumulate there, while thorium and all other elements of the decay chain do not accumulate. These accumulation processes can enrich a certain element of the decay chain.

These enrichment processes are well known in uranium milling, natural oil and gas production and in phosphate ore processing facilities, even though the mechanisms of the processes are not always completely understood. The process is sometimes called “scale enrichment”, although “scale” alone does not cover the whole variety of all phenomena.

The separated nuclides, in Lynas’s processes e.g. Ra-228 and Ra-224, in that case build up their own decay chain locally. Depending upon their half-life time the decay products of the separated nuclides “grow in”, as can be seen from Fig. 3.3.

As can be seen from the figure, the in-growth process in freshly separated Ra-228 requires roughly a year to reach a level of 90% and roughly six years to complete. As in the case of the LAMP the separation process of Ra-228 continues during the operating time of 20 years, the in-growth process accompanies this physicochemical accumulation. Because the in-growth process leads to strong gamma emitting radionuclides, the oldest deposited inventory determines the overall dose rate.

If the enriched nuclides are gamma emitting ones or if their decay chain nuclides are gamma emitters, the resulting local dose rates can be many times larger than the dose rates of the original ore concentrate because the strong shielding effect of the original material composition is lost. Access to areas, repair work, exchanging parts, cleaning work on surfaces or welding can cause high doses, not only by the gamma dose rate but also by inhalation (during cleaning or welding) and ingestion (contact of removed small particles with unprotected skin, subsequent spreading of particles to food and drinks). Any part of the facility that was subject to scale enrichment has to be thoroughly treated during decommissioning and may require specific protective measures.

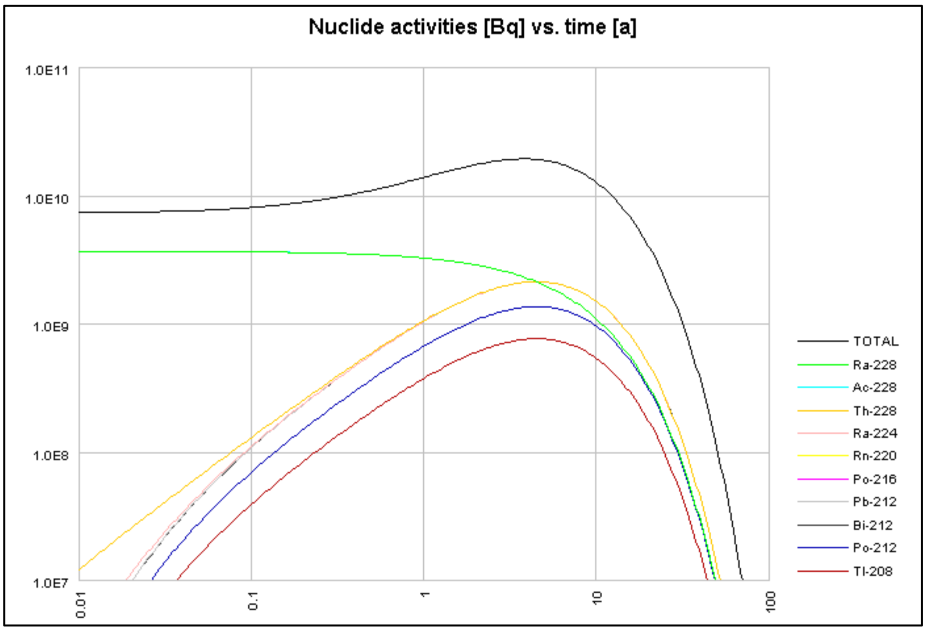


Fig. 3.3: Demonstration of the decay and in-growth process of separated Ra-228 over 100 years, generated with http://www.wise-uranium.org/rcc.html

All nuclides in the thorium decay chain with a half-life time longer than a few months are potential scale sources. In the case of Lynas's facility only thorium and radium come into question, as can be seen from the half-life times in Fig. 3.1. All the relevant nuclides (Th-228, Ra-228, Ra-224) are either themselves gamma emitters or build up gamma emitting nuclides rather quickly. This requires a thorough monitoring for any scale build-up. Fortunately this monitoring can rely completely on gamma dose rate measurements, because no scale-enriched sub-chain has sole alpha emitters, and no extensive alpha scanning is required.

An estimate of scale build-up in the LAMP facility and the resulting consequences are discussed in the Waste section of this study (see Chapter 4.4).

3.1.6 The uranium decay chain

The ore concentrate has 29 ppm of uranium. Uranium's decay chain is different than that of thorium, see Fig. 3.4 for nuclides and half-life characteristics.

The uranium decay chain is only relevant in cases where a high enrichment of scale takes place, namely of Pb-210. Experience teaches that Pb-210 enriches specifically on certain metal surfaces (pipes, etc.). As a consequence, Pb-210 should be included in the monitoring scan and should be considered in any decommissioning of the facility.

Only the U-238 chain is listed here. Because uranium consists of 99.3% U-238 and 0.71% U-235, the complete chain would be more complex. Considering the low content of uranium in the ore concentrate and the small proportion of U-235, the decay chain of U-235 does not make a major contribution to radiation protection issues and is not shown here.

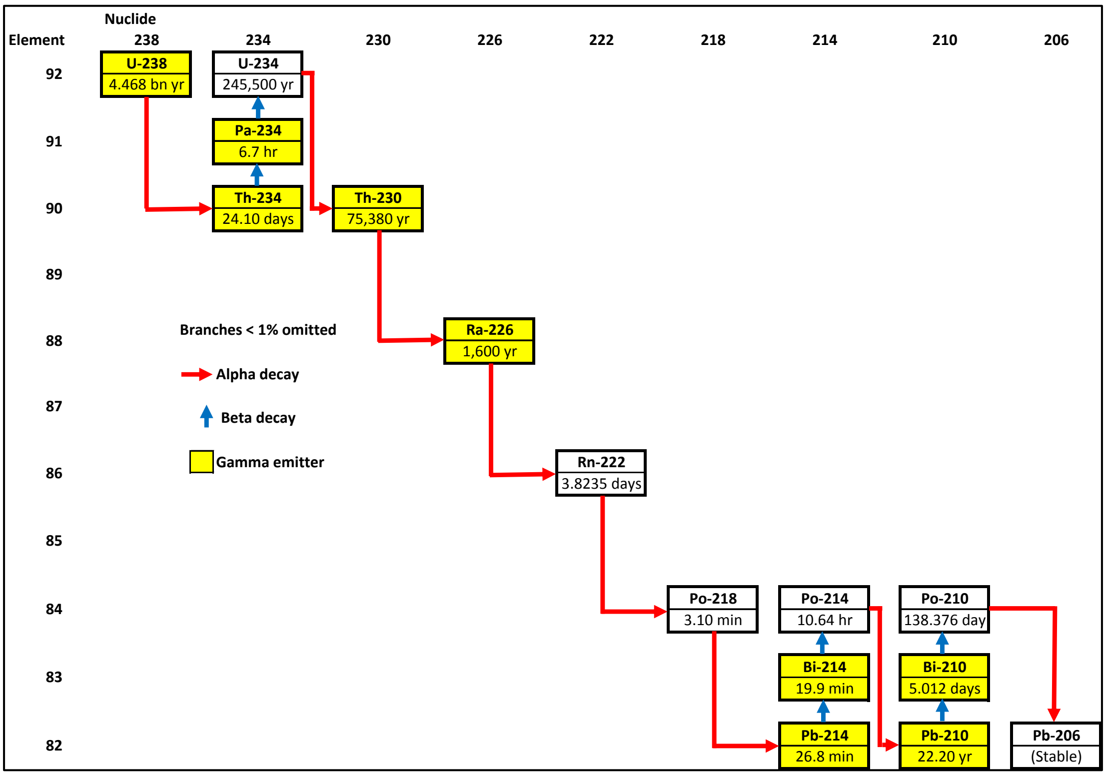


Fig. 3.4: The uranium-238 decay chain (branches < 1% omitted)

3.2 Radioactive emissions from the plant

As has been shown in chapter 3.1.2 thorium builds up its complete decay chain after becoming fixed to a geologic layer (in this case: the lanthanide ore) where it was trapped a very long time ago. All of its decay chain nuclides can be considered to have the same radioactivity concentration (in decays per time and mass unit, Bq/g) as the thorium-232 or uranium-238 itself. All decay products remain mainly entrapped in the solid ore and are only released if the solid matrix of the ore is destroyed. This is the case in the first stage of the process when the ore concentrate is cracked. In this stage it has to be assumed that the complete radon-220 and radon-222 content is released from the solid matrix. Newly produced radon has also to be considered. Once released, the further pathways have to be looked at and, if released to the air, the possible environmental consequences have to be evaluated.

3.2.1 The radon pathway as modelled in the RIA

The radon release pathway is modeled in Appendix C2 of the Radiological Impact Assessment /Bangi Ray 2011/. It assumes for the worst case that due to the decomposition of the solid phase and due to the high temperatures (> 350 °C) the radon in the concentrate is completely released to the gas phase. It calculates the following:

- The feed rate of ore concentrate is 8,372 kg/h.
- The rate of entrapped radon-222 therein and released during cracking to the gas phase is calculated as 731 Bq/s, that of radon-220 as 13,200 Bq/s.
- The generation rate of new radon-220 during the residence time of the ore concentrate in the rotary kiln over three hours is estimated as 1,780,000 Bq/s.
- It is further assumed that 50% of the released radon-220 remains inside the kiln for 0..20 seconds and the rest for 20..35 seconds; an average residence time of 20 seconds in the kiln was selected from that. An additional 47 seconds were selected as average residence time in the waste gas treatment system and the decay of radon-220 was calculated for 67 seconds, resulting in an average rate of 780,000 Bq/s entering the stack.
- The emission of this rate of radon from the stack is then dispersed in the environment. The dilution factor is taken from the respective calculation for the SO_2 dispersion from the stacks, resulting in a factor of $3.8 \cdot 10^6$ m³/s.
- From the release rate at the stacks and the dilution factor, ground level concentrations of $1.9 \cdot 10^{-4}$ Bq/m³ for radon-222 and approximately 0.2 Bq/m³ for radon-220 are calculated. No radioactive decay is considered for the dispersion step.
- The calculated ground level concentrations are then converted to doses assuming equilibrium factors (a measure for the in-growth of the progeny radionuclides of the radon versus dilution in free air, different for in- or outdoors), dose conversion factors for the nuclides and assuming 4,000 hours per year exposure time. The results are 0.004 µSv/a for radon-222 and 0.16 µSv/a for radon-220. These doses are evaluated as “trivial”.

Subsequent calculations compare these results with the exhalation of natural radon from soil.

3.2.2 Critical evaluation

The models applied, the assumptions and the input parameters of this calculation were checked for plausibility. The follow differences and inconsistencies were identified:

- The feed rate used (8,372 kg/h) differs slightly from the 7,420 kg/h that would result from the 65,000 tpa dry ore concentrate in /Environ 2008/ if divided by

8,760 h/a. The difference is plausible if maintenance and downtimes of the rotary kilns are taken into account.

- The rate of entrapped and released radon differs accordingly.
- For the decision to assume 20 seconds average residence time for the release of entrapped and generated radon no further arguments are presented. From a critical point of view this assumption is not justified:
  - Entrapped radon is immediately released to the gas phase when mixing the carbonate part of the ore with sulfuric acid, before feeding it to the kiln, because the initial CO_2 generation carries or tows the associated radon immediately away from the liquid.
  - The radon that is generated during the residence time in the rotary kiln from its predecessor Ra-224 is likely carried or towed away due to the continuous gas generation of the heated mixture (e.g. by vaporized sulfuric acid).

  In both cases the assumption of an average residence time in the rotary kiln of 20 seconds for the released radon is not reasonable and should not have been included to ensure reliable worst case conditions. It further seems to contradict the sentence “the radon in the concentrate is completely released to the gas phase”.
- The dispersion in the environment could not be checked completely, because not all input data is documented. From the description of the models used to calculate SO_2 dispersion it has to be assumed that wind speed and direction data was taken from Exhibit 4.9 of /Environ 2008/, which refers to the data for Kuantan Airport. No clear references are given which data was used for calculating dilution and esp. why exactly this was selected. The models, main assumptions and parameters should have been documented to allow for a review of the complete calculation.
- The decay occurring when dispersing the radon once it was released from the stack. If taken into account, this would lower the resulting doses. In order to estimate this decay time a wind speed of 1.5 m/s (lower bound) and 4.5 m/s (medium bound) and a distance of the most exposed person of 50 m to the stack is assumed. The resulting dispersion times are 33 and 11 seconds, respectively. With a half-life time of 55 seconds for radon-220 these dispersion times are not highly relevant to the overall results.
- The dose conversion factor used for radon-220 stems from a 2006 UNSCEAR publication. In this publication UNSCEAR states on uncertainties of these dose conversion factors: “*It may be that a single dose conversion factor cannot adequately cover the variety of natural and occupational exposure situations.*” /UNSCEAR 2006/. By using those factors an estimate of their uncertainty should be made in all cases where a factor of 2 or more is involved (which is the case here).

- No reasons were given for the assumption that the most exposed person is exposed for 4,000 hours per year. This accounts for roughly 46% of the year. Wind directions cannot be the reason because the main wind direction is from the north for only 25.9% of the year. It is unclear what this assumption is based on.

The comparison with natural background levels, as attached to the calculation, is not worth any review or comment.

3.2.3 Environmental consequences

The resulting doses from the release of radon-220 and radon-222 in the cracking stage of the facility over the stack of up to 0.16 µSv/a are indeed “trivial”. Even if the identified differences and inconsistencies in chapter 3.2.2, esp.

- the uncertain dose conversion factor,
- the unclear exposure time of the most exposed person, and
- the unreasonable assumption of a prolonged delay before the radon is released to the atmosphere,

are exchanged by worst case assumptions, that is: by a factor of roughly 10 larger than stated, the resulting individual risk for the most exposed person under those worst case conditions is less than 10^{-7} per year or less than 1 in 10,000,000 (see Table 3.2, line with “0.01 mSv/a”, divided resp. multiplied by roughly a factor of 6). The environmental consequences of the emission of radon via the stack are negligible.

Collective doses were not calculated for this exposure. This is reasonable because the doses for the most exposed individual is already very small and because the decay chain of radon-220 (other than that of Rn-222) is rather short-lived and so does not add relevant doses in the wider distance.

The dose calculation in /Bangi Ray 2011/ could be better documented to ease the review.

For small risks like the above calculated ones, references to “natural background” are at best misleading. The risk from this industrial undertaking on this pathway is to be accepted as such or not. It does not depend upon other accepted risks whether this risk should be accepted or not. After all, the health damages that this “natural background” causes, and possible steps to avoid or reduce those damages, are the exact and only reason why UNSCEAR writes scientific books such as /UNSCEAR 2006/ - not because there is no damage from natural background but in order to understand those damages more exactly and in order to avoid them.

The results can be summarized as follows:

- The environmental consequences from the emission of radon over the cracking facility's stack are small.
- Even when introducing more strict assumptions in the dose calculation the associated dose and risk remains negligible.
- Small risks should be communicated as such. They should not be compared with natural background, because the natural background risk level is not zero and is not always below acceptable levels, based on given current knowledge and understanding. Such comparisons are in most cases un-scientific and misleading.

3.3 Emissions to air through stacks

3.3.1 Emission processes and their typical spectrum

At the LAMP, two different stages are to be considered as emission sources:

1. the cracking stage (treatment of ore concentrate at high temperatures with sulfuric acid in rotary kilns), and
2. the calcination of oxalates of lanthanum and didymium at 900 °C in a tunnel furnace.

Cracking stage

The stack emitting the off-gas of the cracking stage is the only source of contaminants that are discharged to the air. The following emissions have to be considered:

- Sulfuric acid mist (H_2SO_4) and sulfur trioxide (SO_3): These component stems from heating the ore concentrate with sulfuric acid to high temperatures beyond the boiling point, decomposition to sulfur trioxide included. In contact with water (if emitted: water in air) the trioxide recombines to the acid, so both components are equivalent.
- Sulfur dioxide (SO_2): This component stems from the reduction of sulfuric acid and has very different chemical and biological properties than those of the trioxide and has to be considered separately.
- Hydrogen fluoride (HF): This component stems from the ore concentrate, where fluorides are cracked and converted to HF.
- Particulate Matter (PM): Commonly referred to as dust, those particulates stem from insoluble and un-cracked parts of the ore concentrate (e.g. certain rare earth phosphate fractions) or from the incomplete combustion of gas. These generally small particulates are carried away with the gas stream (CO_2, acid vapor, combustion gases). The smallest particle fractions, with less than 10 µm diameter that are more mobile, are rapidly transported with air and can be inhaled, are referred to as respirable dust or PM_{10}.

Calcination stage

The emissions from the tunnel furnace process include

- Particulate Matter (PM): The particles here consist mainly of rare earth oxides.
- Other materials: Among those are incompletely destroyed oxalic acid and carbon monoxide (CO).

3.3.2 Gas treatment stages at LAMP

Cracking stage

The treatment and removal of acid mist and acidic gases (SO_2, SO_3, HF) as well as PM is performed by a waste gas scrubber system. This applies only for "normal operating conditions". Under these conditions the stack release parameters are 0.05 g/Nm³ for HF and sulfuric acid mist and 0.1 g/Nm³ for PM_{10}. With a gas discharge of the cracker stage of 99,344 Nm³/h roughly 5 kg each of HF and sulfuric acid and 10 kg PM_{10} will be emitted per hour of full operation, which translates into 1.4 g/s or 2.8 g/s, respectively. Another usual term would be to calculate the emitted sulfuric acid per ton of acid introduced into the process to yield a number characterizing the loss rate via emissions. The sulfuric acid used in the plant is 110,238 tons per year. If the gas discharge of 99,344 Nm³/h and 0.05 g/Nm³ is taken for the whole year, 43.5 tons or 0.04% or 0.395 kg/ton of the handled acid is emitted.

As the scrubber system does not work in case of an internal or external power loss, the waste gas is then diverted into "standby caustic scrubbers". These have a lower efficiency for removing sulfuric acid mist (9.9 g/s instead of 1.4 g/s), but a higher SO_2 removal efficiency (1.6 g/s instead of 6.9 g/s). This mode of operation is called "Emergency" mode in /Environ 2008/. Why this design decision has been taken and the treatment system has no uninterruptable power supply (USP) instead is not mentioned.

Calcination stage

The emissions from the tunnel furnace process, mainly PM with rare earth oxides, are not filtered and are released directly to the air, as /Environ 2008/ states. No reasons for the assumption that the emitted particulates are environmentally insignificant are given.

This is in contrast to a similar plant that uses exactly the same calcination process for treating REE oxalate. As described in /Zunckel 2012/ the tunnel furnace off-gas there will be filtered with a simple bag-collector. Following this filter the maximum 1-hr particulate concentration is within regulatory limits. No data is given in this source on the estimated amount of filtered material.

3.3.3 Requirements and calculated impacts

The applicable PM_{10} standards in Malaysia are regulated in Air Quality Guidelines and stem from 1978. The Malaysian Guideline for PM_{10} is 150 µg/m³ averaged over a day and 50 µg/m³ over a year. The regulation for sulfuric acid and sulfur trioxide emissions (at source) is at 0.2 g/Nm³ (or at 3.5 g/Nm³ for sulfuric acid production plants). All cited data was taken from /Environ 2008/.

Apparently the regulation for permissible sulfuric acid emissions is met (0.05 mg/Nm³).

The distribution of the emitted PM_{10} dust was modeled and the Maximum Predicted Ground Level Concentrations (GLC) were calculated. The maxima (four rotary kilns in operation) are 6.5 µg/m³ in 24 hours and 0.7 µg/m³ over the whole year. Thus, the applicable legal requirements are met and only a small fraction (4.3% or 1.4%, respectively) of the limit is utilized.

3.3.4 Regulation, technical improvements, best practice

Over the past forty years,

- dust removal technologies and their efficiency have been significantly improved, while
- knowledge on the adverse health effects of particulates has also improved, these effects were previously underestimated.

/Environ 2008/ recognizes the latter improvement by adding more recent WHO recommendations, showing that the Malaysian regulation of 1978 does not reflect the state-of-the-art as to the adverse health effects from PM_{10}. However, /Environ 2008/ does not apply the more strict WHO recommendations in their evaluation. No reasons are presented why the old Malaysian regulation was selected.

More modern environmental regulation includes both aspects, so that improved technological abilities as well as improved toxicological knowledge can be integrated to form a dynamic regulation, to increase and strengthen environmental improvements and to reduce environmental damages.

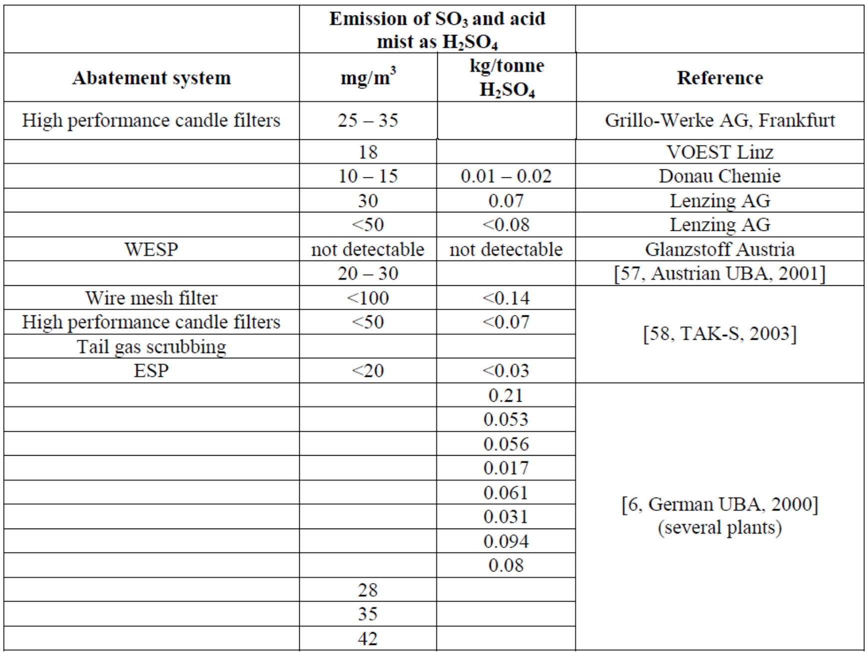
The following two chapters demonstrate the state-of-the-art of emission reduction for sulfuric acid and PM_{10} emissions.

3.3.5 Comparison of sulfuric acid emissions with production plants and best practice

As the efficiency of filters does not depend very much upon the inventory of the facility, removal efficiencies of the LAMP plant can be compared with those of typical sulfuric acid production plants. The two numbers relevant here are the 50 mg/Nm³ emission rate under normal conditions and the 0.395 kg/ton losses through emissions.

/EC 2007/ in Table 3.3 provides emission characteristics of sulfuric acid production plants in Europe.

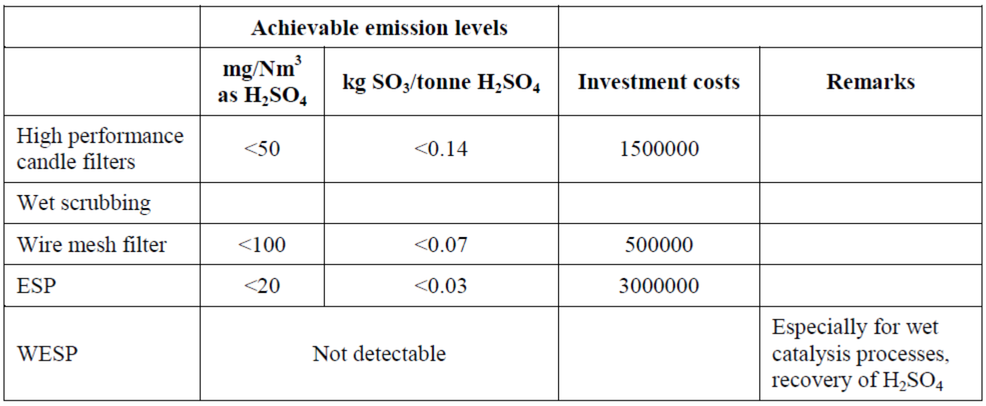
Table 3.3: Emission of sulfur trioxide and acid mist in sulfuric acid production, from /EC 2007/



	Emission of SO_3 and acid mist as H_2SO_4		
Abatement system	**mg/m^3**	**kg/tonne H_2SO_4**	**Reference**
High performance candle filters	25 – 35		Grillo-Werke AG, Frankfurt
	18		VOEST Linz
	10 – 15	0.01 – 0.02	Donau Chemie
	30	0.07	Lenzing AG
	<50	<0.08	Lenzing AG
WESP	not detectable	not detectable	Glanzstoff Austria
	20 – 30		[57, Austrian UBA, 2001]
Wire mesh filter	<100	<0.14	[58, TAK-S, 2003]
High performance candle filters	<50	<0.07	
Tail gas scrubbing			
ESP	<20	<0.03	
		0.21	[6, German UBA, 2000] (several plants)
		0.053	
		0.056	
		0.017	
		0.061	
		0.031	
		0.094	
		0.08	
	28		
	35		
	42		

As can be seen from the figures listed, LAMP's emission rate of 50 mg/Nm³ is by a factor of up to two larger than in most of the listed plants, its loss rate by a factor of at least two and in most cases up to five times larger than in those production plants, with only one plant in the same order of magnitude. It should be noted that the listed data is more than five years old, for many of the listed plants more than ten years old, so that improvements are not adequately reflected.

Table 3.4: Best available technologies to reduce sulfuric acid emissions, from /EC 2007/



	Achievable emission levels			
	mg/Nm^3 as H_2SO_4	**kg SO_3/tonne H_2SO_4**	**Investment costs**	**Remarks**
High performance candle filters	<50	<0.14	1500000	
Wet scrubbing				
Wire mesh filter	<100	<0.07	500000	
ESP	<20	<0.03	3000000	
WESP	Not detectable			Especially for wet catalysis processes, recovery of H_2SO_4

The list of best available technologies to reduce sulfuric acid emissions in Table 3.4 shows that the loss rates are in all cases smaller than LAMP's loss rate, up to a factor of ten (for ESP technology).

The WESP technology, while not always applicable, exhibits the highest performance.

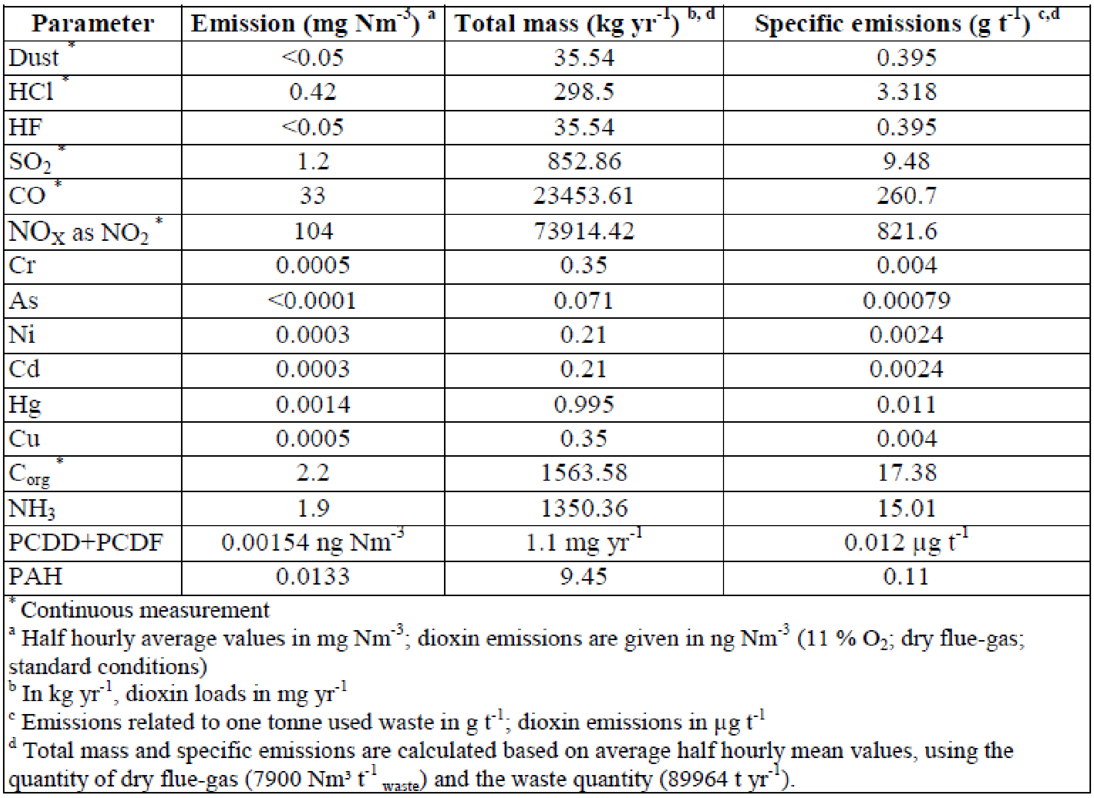
3.3.6 Comparision of particulate emissions with those of waste combustion plants

To compare the particulate emissions of LAMP with those at waste combustion plants is reasonable because the off-gas treatment system is comparable at system level: large amounts of flue gas have to be treated and particulates of different sizes have to be removed from the flue gas.

The relevant figures to be compared here are the 0.1 g/Nm³ or 100 mg/Nm³ for PM_{10} particles.

Selected here is the hazardous waste incinerator at Simmeringer Heide in Austria.

Table 3.5: Emission characteristics of the hazardous waste incineration plant Simmeringer Heide, from /EC 2006/



Parameter	Emission (mg Nm^{-3}) ^{a}	Total mass (kg yr^{-1}) $^{b, d}$	Specific emissions (g t^{-1}) ^{c,d}
Dust *	<0.05	35.54	0.395
HCl *	0.42	298.5	3.318
HF	<0.05	35.54	0.395
SO_2 *	1.2	852.86	9.48
CO *	33	23453.61	260.7
NO_X as NO_2 *	104	73914.42	821.6
Cr	0.0005	0.35	0.004
As	<0.0001	0.071	0.00079
Ni	0.0003	0.21	0.0024
Cd	0.0003	0.21	0.0024
Hg	0.0014	0.995	0.011
Cu	0.0005	0.35	0.004
C_{org} *	2.2	1563.58	17.38
NH_3	1.9	1350.36	15.01
PCDD+PCDF	0.00154 ng Nm^{-3}	1.1 mg yr^{-1}	0.012 µg t^{-1}
PAH	0.0133	9.45	0.11

* Continuous measurement
^{a} Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O_2; dry flue-gas; standard conditions)
^{b} In kg yr^{-1}, dioxin loads in mg yr^{-1}
^{c} Emissions related to one tonne used waste in g t^{-1}; dioxin emissions in µg t^{-1}
^{d} Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (7900 Nm³ t^{-1} $_{waste}$) and the waste quantity (89964 t yr^{-1}).

The plant combusts roughly 90,000 tons of waste per year in two rotary kilns. Its flue gas cleaning system has an electrostatic precipitator that reduces the dust to

10..30 mg/Nm³. This stage is followed by a wet flue-gas cleaning stage and a venturi scrubber for fine dust. Table 3.5 lists its emission data.

Note that already the first stage of the dust removal system reduces dust to a factor of three or more lower than for the LAMP plant, the second stage to even smaller concentrations. Finally the resulting dust emissions are below detection limits of the continuous measurement equipment.

The data shown here is not at all cutting-edge technology but already 12 years old. Further improvements in emission reduction have been made since then.

Other plants can also be taken as similar examples with similar results.

3.3.7 Conclusions for emissions to the air over stacks

The analysis and comparisons shows that

- no reasons are given for the decision to operate the calcination stage without a waste gas treatment system, while other similar examples show that at least a simple dust removal method should be used,
- the static Malaysian environmental regulation in respect to air quality is inappropriate, because it neither reflects improved knowledge on adverse toxicological effects nor does it encourage improved technical capabilities to reduce emissions; the regulation should be improved by adopting dynamic limits taking advantage of technical improvements to reduce environmental burdens,
- the treatment systems of Lynas for abating emissions of acidic gases and acids as well as for dust are neither state-of-the-art nor best-available-technology and cause sulfuric acid emissions that are too high by a factor of at least two and PM_{10} dust emissions that are too high by an even larger factor.

3.4 Emissions to water through discharges

This chapter evaluates emissions to water through discharges. Chapter 3.4.1 provides information on the initial concentrations of process water. The treatment of wastewater is discussed in chapter 3.4.2. Chapter 3.4.3 describes the discharge water path and the environmental consequences along that path. The results are summarized in chapter 3.4.4.

3.4.1 Wastewater sources and their initial composition

The following sources of liquid effluent have to be considered:

- the chemical processes to mill the ore and to produce rare earth components, as described in chapter 2.2; the amount of water to be discharged from the chemical process is in the range 330 to 500 m³/h /Environ 2008/,
- supernatant liquors and surface runoff from the Waste Storage facilities,

- six further sources of water.

In the following, only the first two of those sources are discussed.

REEs in the wastewater

For a facility separating rare earth elements it should well be known how large or small the losses of REE to the wastewater stream will be and how effectively the separation/filtration technologies will work and how complete the wastewater treatment process is able to remove traces of these compounds prior to its discharge. No accessible document, including the PEIA study /Environ 2008/, mentions rare earth elements as part of the wastewater. Even though these losses are expected to be in the ppm-range, given their typical chemical characteristics, these elements should at least appear in the list with their expected concentrations, prior to and post treatment plant. Also, their maximum wastewater concentrations should be clearly specified. This specification should be based on their toxicity characteristics, taking the limited knowledge and the wide uncertainties (see chapter 2.4.1) into account by defining cautious limitations and and assuring by optimization of the plant's operating modes that the emissions stay well below these limitations. The wastewater content should be monitored and set as a clearance criterion for the release of wastewater.

This lack of defining, monitoring and limiting REE in the discharged wastewater is completely inappropriate. This lack should have been identified in the PEIA, discussed as an issue and included in a separate list of plant-specific emissions, for which no formal limits are applying in the Malaysian regulations, but for which limits are to be specified based on best available current knowledge.

Toxic materials[5] in the wastewater

Ores typically consist of a large variety of content because the same processes that lead to the concentration of the rare earth elements in the ore also concentrate other metals (such as lead), amphoteric elements or semi-metals (such as arsenic) or non-metallic content (such as fluoride). This "unwanted" content is usually termed "by-product". Milling the ore in the LAMP means that by treatment with chemicals most of the ore content, as well as the by-products, are solubilized and, finally, either end up insoluble in a waste stream or soluble in the wastewater. During wastewater treatment stages, those substances are either immobilized and are contained in treatment sludges or remain in solution and are discharged. In order to determine the type and amount of toxic materials and its fate it is necessary to know

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[5] The term "toxic materials" is used here for scientific correctness instead of the term "heavy metals", because some of the toxic constituents deserving attention aren't neither "heavy" nor "metals" e.g. arsenic or fluoride.

their content in the ore and to understand their chemical behavior in the chemical process and in the wastewater treatment stage.

None of the accessible documents, including the Environmental Impact Assessment /Environ 2008/, has a list of the average and bandwidth of by-products in the ore. It is simply unknown which by-products are part of the ore and whether this content is in a relevant range or not. An analysis of this sort should be the base of any environmental assessment. The absence of this analysis is below any acceptable standard for an impact assessment.

Very few data in the documents refer to such by-products. /Environ 2008/ lists for the output of the wastewater treatment its content of copper, zinc, manganese, lead, tin and iron and compares this with Malaysian Standard B. No reference is given for the data, how the numbers have been gained, why certain components (cadmium, mercury, arsenic, boron and chromium) were not even determined[6], even though those are defined in the cited Malaysian standard. The Safety Case /Environ 2011/ lists manganese, zinc, chromium (with an unknown oxidation state), lead and nickel with more than 100 ppm and cadmium, arsenic and cerium with less than 100 ppm as constituents of the WLP waste stream (see Table 4.2).

The license document /Pahang 2008/ just repeats Environ's proposal and does not establish additional requirements.

No reliable methods exist to conclude from this sparse information on the content of by-products and their environmental relevance. Just stating these information cannot provide reliable evaluation in respect to the wastewater.

It has to be concluded that no thorough analysis of characteristics of the wastewater is possible due to the serious lack of data for toxic materials entering the plant and leaving it with the wastewater.

Salt loads of the wastewater

Major input components of the LAMP facility are acids (sulfuric and hydrochloric acid) and alkaline chemicals such as lime and magnesium oxide to neutralize those acids. The wastewater treatment plant is not designed to remove or reduce this salt freight (see chapter 3.4.2). The PEIA neither calculates the salt load in the wastewater nor does it discuss the associated environmental consequences.

Usually the salt load of (waste)water is monitored or limited by the conductivity. Salt increases the conductivity, so the salt content can simply be expressed as conductivity and vice versa. Conductivity is a measure of water quality and of the same importance as the pH or Eh value (alternatively: free oxygen content).

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[6] While Table 5.2.6 in /Environ 2008/ does not define the meaning of "-", it is interpreted here as "not determined". To interpret a "-" as "not determined" is reasonable because components such as tin or iron are listed with their detection limit.

In its comparison with the Malaysian standard /MY Reg 1979/, /Environ 2008/ does not list the pH of the wastewater. The Malaysian standard does not list conductivity as a criterion, sulfate and chloride are only listed from which to calculate financial parameters from. Thus it is currently not requested by national regulation to specify the salt content, even though the salt content is an indicator of water quality and serious environmental damages can result if salt-rich wastewater enters freshwater resources.

Table 3.6: Salt balance for the input and output streams

Ion	Input/Output stream	Amount, tpa	Waste streams	Stream tpa
Sulfate	Sulfuric acid, 98%	110,238		105,828
	WLP waste	64,000	Aluminum sulfate	-197
	NUF waste	117,820	Calcium sulfate (gypsum)	-48,311
	FGD waste	58,920	Calcium sulfate (gypsum)	-31,227
	To wastewater:			**25,793**
Chloride	Hydrochloric acid, 36%	146,776	**To wastewater:**	**51,392**
Magnesium	MgO	23,348		14,081
	WLP waste	64,000	Magnesium sulfite	-439
			Magnesium carbonate	-281
			Magnesium phosphate	-26
			Magnesium hydroxide	-8
	NUF waste	117,820	Magnesium hydroxide	-8,596
	FGD waste	58,920	Magnesium fluoride	-138
	To wastewater:			**4,592**
Calcium	Lime	111,386		79,607
	WLP waste	64,000	Calcium phosphate	-403
			Calcium sulfate	-15
			Calcium carbonate	-26
			Calcium uranate	-0.22
	NUF waste	117,820	Calcium sulfate	-20,130
			Calcium hydroxide	-2,547
			Calcium carbonate	1,885
			Calcium oxalate	-552
	FGD waste	58,920	Calcium sulfate	-13,017
			Calcium hydroxide	-1,274
			Calcium carbonate	-24
	To wastewater:			**39,734**
Sodium	Soda ash	19,632	**To wastewater:**	**8,520**
Total			**To wastewater:**	**78,639**

The salt load of the discharged water can be calculated performing a mass balance for the plant. The basic principle is that ionic masses entering the plant either are transferred to waste streams or to the wastewater to be discharged. This calculation is shown in Table 3.6 for the anionic species sulfate and chloride as well as for the cationic species of magnesium, calcium and sodium. Inputs and wastewater outputs are indicated by a positive sign, proportions leaving the process via waste streams are listed with a negative sign.

A total of about 78,639 tons of alkali- or earth alkali salts leaves the process via the wastewater stream, the majority (ca. 50%) being calcium chloride.

If

- this yearly amount is divided by 8,760 hours per year, and
- the lower bound of water consumption of the LAMP of 330 m^3/h is used to calculate the salt content of the wastewater,

a salt concentration of 2.7% in the wastewater results. This can be compared with

- the average seawater salt content (mainly sodium chloride) of 3.45%,
- the limit for water used for irrigation of 0.2%, which is thus lower by a factor of 13,
- the limit for drinking water of 0.05%, by a factor of 54 smaller, and
- an average drinking water salt content of 0.01%.

The salt content of the wastewater is of relevance, its environmental consequences have to be evaluated.

3.4.2 Wastewater treatment

Wastewater is first neutralized by adding lime or soda ash. The resulting sludges are dewatered and stored as waste (NUF waste stream, see chapter 4.1.2). /Environ 2008/ states that the neutralization process also reduces heavy metals[7] and Total Suspended Solids (SS) to below the necessary standard concentrations. In /Environ 2008/ the Chemical Oxygen Demand (COD) of 2,000 mg/l of this neutralized wastewater is identified as the only parameter that requires further treatment prior to discharge, because it is by a factor of 20 above the standard and by a factor of 80 to 30 above the COD of Sungai Balok.

To reduce the COD, the wastewater is then treated with Sequential Batch Reactors, for which no further descriptions and specifications are given. The further COD values used in /Environ 2008/ are either 100 or 2,000 mg/l, with the second value used for the Worst Case Scenario.

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[7] This might be correct for most of the Heavy metals, but not for all potentially hazardous materials in the ore, e.g. for arsenic. As there is no quantitative analysis for the ore concentrate is available, no environmental evaluation can be made.

The wastewater is then collected in a settling pond. After analysis and compliance with Standard B requirements the water is transferred to the storm water detention pond and finally discharged through the discharge point (see Fig. 3.6).

It should be noted that the wastewater treatment plant does not remove or alter the magnesium, chloride or sulfate content of the water. By adding the soda ash, the sodium is introduced in this stage and the sodium is completely discharged. The salt concentration calculated above is diluted when the wastewater enters the settling pond and is transferred to the storm water detention pond. The dilution factors are higher in case of the rainy season, but might reach a dilution of zero if no precipitation occurs over several weeks of operating time. So the whole bandwidth up to the maximum calculated as well as changing concentrations have to be considered.

3.4.3 Wastewater discharge

Fig. 3.5 shows the further route of the discharged water. Together with soakage from the swamp layer of the peatland, the discharged waste water is transferred in an earthen channel over three km distance into the Sungai Balok (green arrow).

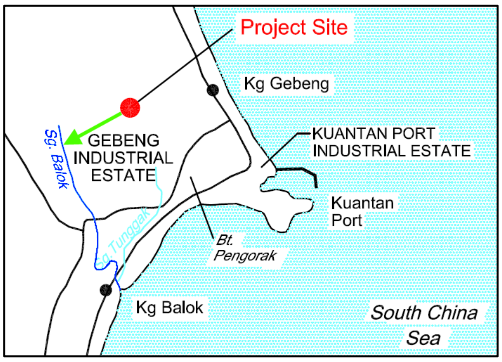


Fig. 3.5: Overview of the discharge water path, modified from /Environ 2008/

Fig. 3.6: Lynas discharge channel

The following picture was taken on 24th of December 2012 in the monsoon season.

Abb. 3.7: Lynas discharge channel in the monsoon season, photo taken and ©2012 by Mr. Tan Bun Teet

After discharge the wastewater mixes with water from the swamp layer of the peatland (Fig. 3.8, from left and right, combined flow towards bridge).

Fig. 3.8: Waterfall at initial mixing point and channel

The earthen channel combines with other water channels (see Fig. 3.9; from the right: brownish soakage from the swamp layer) and flows towards Sungai Balok. The channel's bed has in part been broadened to accommodate the flow (see Fig. 3.10).

Fig. 3.9: Discharge channel from the left, further water movement to foreground

Fig. 3.10: Further path of wastewater towards Sungai Balok, approx. 3 km long

For this flow path the following aspects have to be considered:

- No signals on this flow path indicate that this channel is a wastewater discharge channel.
- The water flow in the earthen channel is free to be accessed by animals and humans.
- Seepage can transport water to the groundwater level. Subsequently salty water will be transported with groundwater flow in an unknown direction.
- Mud and sediments in that channel can accumulate, absorbing the toxic substances discharged and concentrations well above that of the discharged water can be reached. Access to these potential sources of toxic materials should only be allowed after thorough monitoring for such substances.
- Dynamically developing salt concentrations tend to reduce biological diversity, because only adapted species are able to live in salty water and in sweet water.
- Reduced biological diversity also means that anaerobic conditions can establish, at least in the mud and sediment zone. The resulting microbiological reduction of sulfate to sulfides and/or hydrogen sulfide would be enabled, leading to further reduction in biological diversity and to toxic conditions.

Hence, this discharge channel for wastewater is an inadequate solution. More effective and appropriate would be to transfer the treated water in a pipeline. As the salt content is an issue, its transfer directly to the nearby sea would be the most appropriate solution. This discharge mode should have been adopted for all wastewater sources that can be saturated with gypsum (runoff from storage facilities), while collected and uncontaminated, but monitored precipitation could have been directed to this channel.

After roughly 3 km on this flow path, the discharged water reaches Sungai Balok.

Fig. 3.11: Sungai Balok fishing harbor

Unlike the expectation in /Environ 2008/ the discharged water will not mix immediately with the complete water flow of Sungai Balok, especially when flow velocities are small (which is the case). Mixing of water can require several km in flow direction, so therefore the assumption in /Environ 2008/ that Sungai Balok dilutes the discharged water by a factor of 150 is only reasonable after a long flow path. As a dilution of the salt content to one tenth of the concentration in the facility's wastewater is required to achieve irrigation quality, the initial mixing with water in the Sungai Balok is able to provide this. Major environmental consequences for Sungai Balok from the salt content are not to be expected.

Sungai Balok finally arrives at the South China Sea (see Fig. 3.12). As the dilution there is even larger, the salt content does not play a role at this point of the pathway. Not so the COD: /Environ 2008/ assumes that untreated water with a high COD of 2 g/l can enter Sungai Balok over short periods, if treatment and dilution fails. This fact is downplayed by mentioning that the COD in Sungai Balok water is already high and that different sources add up together. In that case it would be more appropriate to not add another source but to improve the overall water quality by removing or reducing the other sources.

Fig. 3.12: Sungai Balok mouth (center of picture) and touristic coastal area

It is a serious lack that the chemical constituents that cause this high COD are not identified and named. A high COD can as well be caused by inorganic (e.g. ammonia or nitrite) and organic compounds, the measuring principle for the COD provides no hints on the causes. Less probable is that the high salt content is causing this because neither sulfate nor chloride nor sodium and magnesium are affecting COD results. In case of a COD of 2 g/l it has to be expected that the component is present in concentrations of several hundred milligrams per liter, a considerable high concentration if the compound is chemically toxic.

3.4.4 Conclusions from the critical evaluation of wastewater discharges

The following conclusions can be drawn from the above analysis:

- The documents, including the Preliminary Environmental Impact Study, do not provide information on the by-product content of the ore concentrate. No balance calculations can be made for other toxic constituents of the ore.
- The analysis of process water prior to its treatment considers only those constituents which are mentioned in the Malaysian Water Quality requirements for effluents. The analysis even leaves out some of the species listed there without naming reasons for that.
- Specific constituents of the wastewater of the LAMP facility such as rare earth elements and salt are not even mentioned, their concentrations are not calcu-

lated and the environmental consequences are not identified, discussed and evaluated, as it would be required in a Preliminary Environmental Impact Study.

- A detailed calculation of the salt content of process water was performed and it is shown that the salt content (mainly calcium chloride) is only slightly below that of average seawater and by a factor of at least 15 higher than the water quality that can be used for irrigation. The salt is not removed in the water treatment stages and will be discharged completely.
- The transport of the discharged water with toxic constituents, a frequently high chemical oxygen demand and high salinity in an open earth channel, accessible by humans and animals, is unacceptable. Water of this low quality should be transported in a pipeline that does not allow seepage to escape to the groundwater and prevent unintended water use.
- The already high chemical oxygen demand of Sungai Balok should not be further increased by allowing to discharge additional COD. The approach should be to remove and reduce those sources, in order to improve the water quality.

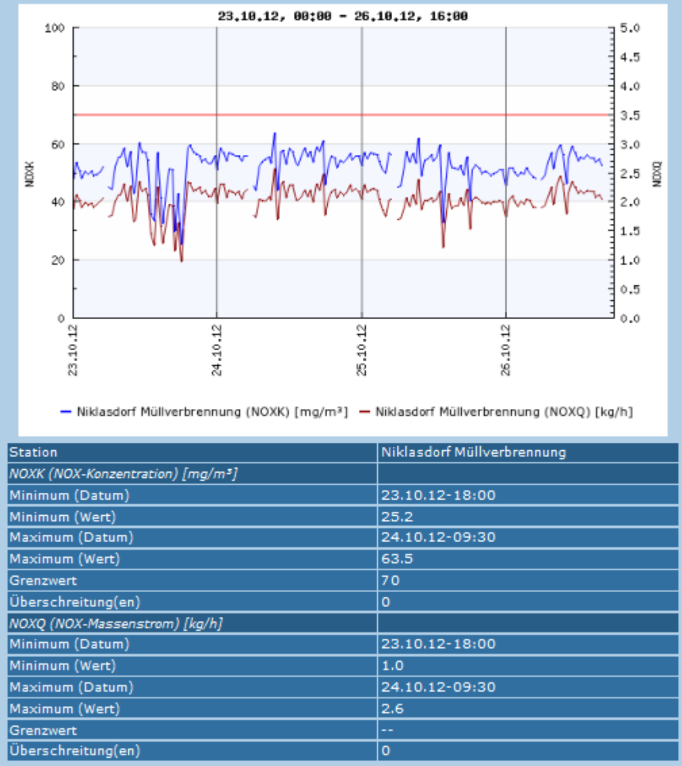
3.5 Online documentation of emissions

In the European Union a right-to-know exists on environmental data. This right extends to federal and state agencies. On request by citizens the responsible agencies have to copy their data and make them available to citizens.

Modern process control and continuous monitoring of emission parameters over the air and water pathway make it possible to bring the raw data immediately online, so this data can be made directly publicly accessible.

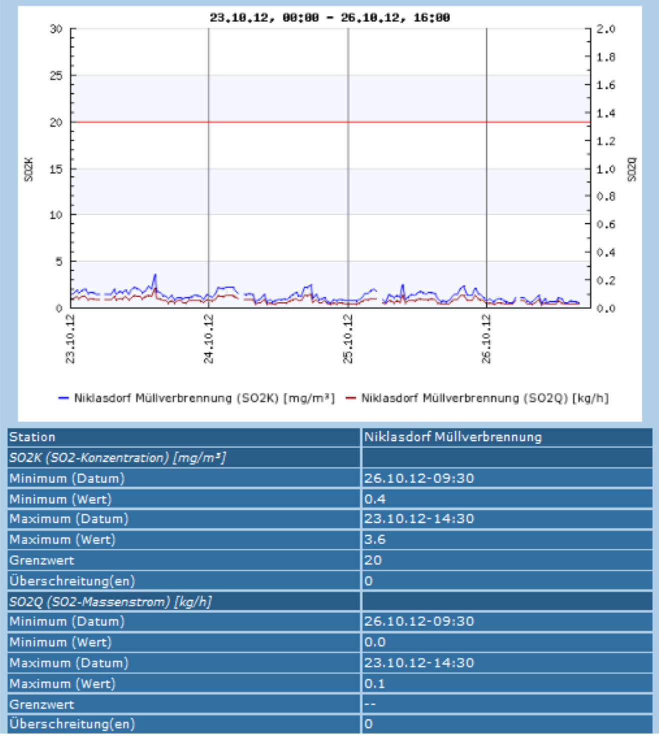
Fig. 3.13 (NO_X) and Fig. 3.14 (SO_2) provide a screenshot of such a web interface for a garbage waste combustion plant in Austria.

The web interface allows for a user-selected display of the emission monitoring data for a certain period of time (Fig. 3.15 for dust).



Station	Niklasdorf Müllverbrennung
NOXK (NOX-Konzentration) [mg/m³]	
Minimum (Datum)	23.10.12-18:00
Minimum (Wert)	25.2
Maximum (Datum)	24.10.12-09:30
Maximum (Wert)	63.5
Grenzwert	70
Überschreitung(en)	0
NOXQ (NOX-Massenstrom) [kg/h]	
Minimum (Datum)	23.10.12-18:00
Minimum (Wert)	1.0
Maximum (Datum)	24.10.12-09:30
Maximum (Wert)	2.6
Grenzwert	--
Überschreitung(en)	0

Fig. 3.13: Online display of NOX emissions of a waste combustion plant in Austria, taken from /Steiermark 2012/



Station	Niklasdorf Müllverbrennung
SO2K (SO2-Konzentration) [mg/m³]	
Minimum (Datum)	26.10.12-09:30
Minimum (Wert)	0.4
Maximum (Datum)	23.10.12-14:30
Maximum (Wert)	3.6
Grenzwert	20
Überschreitung(en)	0
SO2Q (SO2-Massenstrom) [kg/h]	
Minimum (Datum)	26.10.12-09:30
Minimum (Wert)	0.0
Maximum (Datum)	23.10.12-14:30
Maximum (Wert)	0.1
Grenzwert	--
Überschreitung(en)	0

Fig. 3.14: Online documentation of sulfur dioxide emissions of the same plant, from /Steiermark 2012/

The displayed examples are published by the supervising state agency. To achieve a reliable quality these activities have to be embedded in a formal framework. In order to work they require a certain self-perception of the supervising agency and the operating company, and a certain understanding in respect to the right of the public to know and understand environmental data.

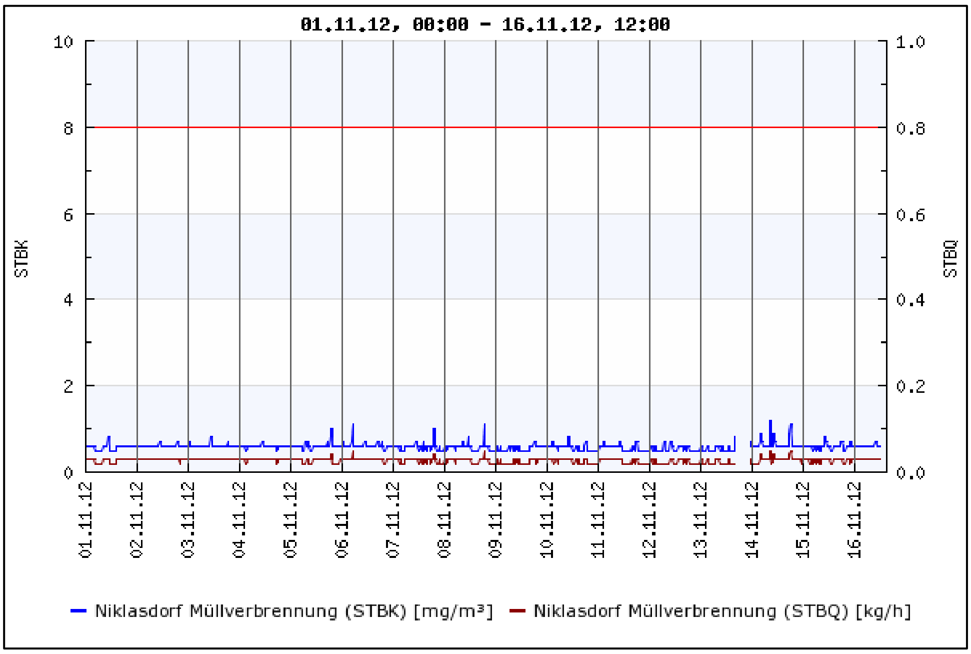


Fig. 3.15: Emission data for dust over two weeks, generated with /Steiermark 2012/

3.6 Hazard control issues

Large chemical plants are always vulnerable to

- equipment failures and malfunctions (tanks, pipes, valves, instrumentation and control, etc.) by ageing, by corrosion, etc.,
- explosions and fire including their consecutive events,
- operating and handling errors by human failure, e.g. induced by errors in procedures, communications,
- natural impacts such as thunderstorms and lightning strikes, seismic events and their effects, flooding, extreme wind, etc.,
- man-made impacts such as plane crashes, sabotage, terrorism, war and civil war.

Based on the hazards involved, the layout of the plant and the operating conditions have to ensure that the appropriate spectrum of possible impacts is adequately covered.

The typical hazards and their environmental consequences that have to be considered here are:

- unfiltered acid vapor loss to the atmosphere,
- leakages of chemicals (acids, extraction liquids, etc.) and their spreading on the ground and to groundwater,
- fire hazards and fire extinguishing liquids and their spreading on the ground and to groundwater.

3.6.1 Perceived environmental consequences of incidents and accidents

The PEIA /Environ 2008/ discusses impacts only in respect to the groundwater (second and third bullet in the above bullet list of hazards). The following mitigation measures are mentioned:

- Fuel tanks and reagent storage tanks are sited on sealed areas with concrete-bunded enclosures capable of containing 110% of the tank content. The floor shall be concrete and lined with an impermeable layer.
- Instrumentation and control/trigger to sound an alarm in case of overfilling and unexpected loss,
- Operational control and inspections,
- Handling areas for liquids shall be paved,
- Accidental spills shall be assessed on a case by case basis and cleaned up,
- Clear work instructions,
- Procedure development, and
- Corrosion protection for steel tanks and their related equipment.

In respect to groundwater a monitoring plan and procedure shall be implemented and monitoring wells be placed up- and downstream, in order to identify and remove potential contaminants.

3.6.2 Evaluation of these mitigation measures

The following problems with these measures have to be considered:

- In case of a massive leakage of a tank, a simple concrete pool might not be able to withstand concentrated sulfuric and hydrochloric acid long enough before emergency measures (removal of the acid, including “bleeding” of the tank’s content) are completed. Pools for these chemicals have to be lined to withstand aggressive acids long enough. It is unclear from the description if this is meant by “impermeable layer”. If so, the quality requirements for the resistance properties would have to be specified.
- Concrete is a material that develops cracks from the very outset, when the reaction that solidifies concrete has reached its end, the reaction heat diminishes and the already solidified concrete cools down. Those cracks become wider

with ageing and when under mechanical pressure, especially under tensile stress. The placement of tanks on top of the concrete pool, with no distance between the tank's bottom and the pool's top side, does not guarantee that leakage of a tank's bottom is detected, because the leakage rather takes the direct path through the cracks. Only if the leakage is massive and exceeds the flow capability through the cracks, can leakage be detected on the side of the pool.

- Inspection can only detect cracks in the concrete pool where the tank does not stand. Inspection measures are therefore incomplete if not enabled by design.
- An assessment of leakage that has already reached the soil layers is simply not appropriate. This leakage has to be removed in any case, be it above the Dutch criteria for soil contamination or not, because the permit to operate a chemical facility does not include a permission to irreversibly contaminate the soil. Contaminating the soil underneath is not covered by and not included in the permit. The Dutch criteria apply for historic contamination that has been found and for answering the question whether there is a strict necessity to remove it because it is too dangerous to leave it there. The question that is answered by the Dutch list is "Is it necessary to remove detected contamination to avoid serious health consequences?". The Dutch list cannot be used to answer the question "To what degree can a clean environment be contaminated by a planned activity?". Usually there are several orders of magnitude between these two different answers, but at least one order of magnitude to be sustainable. To not understand the difference between a planned and permitted activity and a clean-up activity afterwards reveals a serious lack of understanding of basic environmental protection philosophy.

The proposal to monitor groundwater at the site is appropriate, but not for detecting leakages. In reality local leakage may flow one meter to the side of the monitoring well and the well is then simply "blind". If placed further away from a tank to broaden the "angle of view" of the well, the delay between leakage and well detection is in the order of years and allows contamination of several hundred meters of groundwater and soil. Monitoring groundwater therefore is an entirely inappropriate method for leakage detection.

Tank leaks as a possible event scenario to be prevented for has been identified by the regulator:

> *"Concerning the Sixth Ground of Appeal of the Applicants, I know that AELB had taken into consideration the comments on the viability of the containment tanks be built and leaching and subsequently had instructed LYNAS to present a report on the safety design of those tanks. LYNAS had presented its report on those designs and had been certified by the Chartered Engineer Mecip (M) Sdn. Bhd. verifying that the construction of these tanks complied*

> *with specifications and the British Standard best practice international standards." /MOSTI 2012/*

These precautions cannot be evaluated because checking the quality of the design is beyond the scope of this study. Checking those designs, verification of the construction and testing prior to initiate operation should be a mandatory task and should not only be performed if comments are made and point to weaknesses.

3.6.3 Issues that have not been considered

The two most relevant cases,

- an equipment or pipe failure between the rotary kiln and the gas treatment stage, involving by-pass of the treatment stage and massive losses of vaporized sulfuric acid to the atmosphere, and
- a loss of extraction liquid and a fire in the purification or extraction stage, involving subsequent fire extinguishing measures and the spreading of extinguishing liquids,

have not been identified as a possible accident, and their environmental consequences have not been described and assessed.

The probability that such events might occur are elevated because the ground settling characteristics of different stages of the facility are not homogeneous. This is because the thickness of the underlying swamp layer varies greatly (see 4.2.1 for a description of the underground layers and their thickness) and the ground has obviously not been thoroughly prepared to accommodate for heavy equipment installation.

3.6.4 Conclusions on hazard control issues

The analysis and the potential consequences of specific hazards of the plant for the environment

- have not been adequately assessed (tank spill control measures), so that unacceptable consequences for soil and groundwater would result, or
- have not been taken into account (sulfuric acid vapor release, fire extinguishing liquid loss), so that their potential consequences have not been assessed.

4 Wastes arising from operation

The Lynas facility generates wastes. Their characteristics are described in chapter 4.1. The waste storage on the site is evaluated in chapter 4.2. Chapter 4.3 evaluates the operational issues of the storage facilities. Unusual wastes and their properties are evaluated in chapter 4.4. The long-term management options for the wastes are evaluated in chapter 4.5. Issues concerning the decommissioning the Lynas facility are evaluated in chapter 4.6.

4.1 Waste streams and their characteristics

The three waste streams stem from three different stages in the plant and therefore have a very different composition. Their characteristics are described in the following chapters.

4.1.1 The WLP waste stream

The WLP waste stream stems from the initial stage, where the ore concentrate is digested with sulfuric acid and calcined. Then water is added to leach the solubilized portion, the insoluble remnant of that leaching is separated and is Water Leach Purification (WLP) waste. The chemical composition of this waste stream is given in Table 4.1.

Table 4.1: Mineral composition of the WLP waste stream, from /RWMP 2011/

Compound	WLP, wt-%	Compound	WLP, wt-%	Compound	WLP, wt-%
$FePO_4\cdot 5H_2O$	54	$Al_2(SO_4)_3\cdot 16H_2O$	1.7	$La(OH)_3$	0.1
SiO_2	8	$NdPO_4\cdot 3H_2O$	1.3	$Ce(OH)_3$	0.1
$MgSO_3\cdot 7H_2O$	6.5	$Ce_2(CO_3)_3\cdot H_2O$	0.4	$Nd_2(CO_3)_3\cdot 5H_2O$	0.1
Fe_2O_3	5.5	$PrPO_4\cdot 4H_2O$	0.4	ThO_2	0.1
$Fe(OH)_3$	4	$Mg_3(PO_4)_2\cdot 5H_2O$	0.2	$Nd(OH)_3$	0.05
$Al(OH)_3$	3	$La_2(CO_3)_3\cdot 5H_2O$	0.2	$Mg(OH)_2$	0.03
$CePO_4\cdot 4H_2O$	3	$Th(PO_3)_4\cdot 4H_2O$	0.12	$Pr_2(CO_3)_3\cdot 5H_2O$	0.03
$MgCO_3\cdot 3H_2O$	2.5	Al_2O_3	0.1	$Pr(OH)_3$	0.01
$Ca_3(PO_4)_2\cdot 4H_2O$	2	$CaSO_4\cdot 2H_2O$	0.1	$CaUO_4$	0.003
$LaPO_4\cdot 4H_2O$	2	$CaCO_3\cdot 2H_2O$	0.1	**Total**	**95.643**

Table 4.1 accounts for 95.6% of the material. It can be assumed that the majority of the remainder is water. No data on this pore water's characteristics is available. No information on non-radiologic trace elements (such as cadmium, lead, arsenic, etc.) are given in this table.

This additional information is given in /Environ 2011/ and listed in Table 4.2. The column in the source listing the bandwidth of concentrations for these elements in soils in Malaysia has been omitted because mineral forms, release characteristics from the waste (leachability), mobility, transfer characteristics to plants, etc., are incomparable with natural soils, unless all these characteristics have been measured and carefully assessed, so this column does not provide useful information and is misleading.

Table 4.2: Additional elements in the WLP waste stream, from /Environ 2011/

Element	Concentration	Element	Concentration
Al	1.11 wt-%	Ce	79.6 mg/kg
Ca	0.30 wt-%	Mn	2.89 g/kg
Fe	17 wt-%	Ni*	111 mg/kg
Cd	8.2 mg/kg	Pb	490 mg/kg
As*	12.9 mg/kg	Zn	946 mg/kg
Cr**	795 mg/kg		

* Ca is listed in the original table again, but the text includes As in a similar concentration, so it is assumed that As was meant; NI is listed, but no such element is known so it is assumed that Ni was meant.

** No discrimination was made for Cr-III and Cr-VI.

No leachability characteristics were provided in the accessible documents.

Contradicting information is given about the ThO_2 content (0.1 wt-%). The 0.1% ThO_2 given in Table 4.1 would correspond to 0.088 wt-% (minus its oxygen content). According to the text in /RWMP 2011/, on page 29, experimental measurements (there citing Bangi Ray 2011, original inaccessible) indicate that over 99% of the thorium and radium in the ore concentrate enter the WLP waste stream. These experimental results are as expected, because

- Thorium is only soluble in hot concentrated sulfuric acid, dilution with water will render thorium insoluble, and
- Radium is rather insoluble in a sulfate-rich environment.

Therefore most of the inventory of these two nuclides introduced with the ore concentrate is expected to leave the leaching process with the WLP waste stream. The documents /Environ 2008, RWMP 2011/ do not hold the necessary relationships between the ore concentrate and the related WLP waste stream (in tons WLP per ton ore, density in t/m^3 of the WLP waste, etc.). So no complete plausibility check can be made on whether the data given in the various documents is consistent overall.

4.1.2 The NUF waste stream

The Neutralization Underflow residue (NUF) waste results from the neutralization of the hydrochloric acid-rich leachate with lime ($CaCO_3$) and soda ash (Na_2CO_3). Its composition is listed in Table 4.3.

Table 4.3: Chemical composition of NUF waste, after /RWMP 2011/

Compound	**NUF, wt-%**
$CaSO_4 \cdot 2H_2O$	73.5
$Mg(OH)_2$	17.5
$Ca(OH)_2$	4
$CaCO_3$	2
CaC_2O_4	1.5
$LaPO_4$	1.5
Total	**100**

Additionally: Activity concentration of nuclides of the Th-232 and U-238 decay chain is at 0.52 Bq/g

4.1.3 The FGD waste stream

The Flue Gas Desulfurization process captures sulfuric Acid by neutralizing the gas stream with lime ($CaCO_3$). The composition of the resulting FGD waste is given in Table 4.4.

Table 4.4: Chemical composition of FGD waste, after /RWMP 2011/

Compound	**FGD, wt-%**
$CaSO_4 \cdot 2H_2O$	95
$Ca(OH)_2$	4
SiO_2	0.6
MgF_2	0.3
$CaCO_3$	0.1
Total	**100**

Additionally: Activity concentration of nuclides of the Th-232 and U-238 decay chains is at 0.47 Bq/g

4.1.4 Leachate characteristics of the waste streams

No information is available on the leachate characteristics of these wastes. Leaching tests mix a certain amount of the waste with water or with a defined solution, wait for a certain reaction time (either under active mixing or not), separate solids and dissolved material and analyse the content of the soluble and insoluble phase.

Leaching tests and their results should have been used to determine

- leachate water quality (in order to be able to evaluate the potential environmental consequences of leachate releases to the environment),
- storage safety characteristics to base the design and quality of geo-mechanical barriers on this information,
- groundwater protection requirements such as layer thicknesses, hydraulic conductivities,
- model parameters for pollutant spreading (e.g. for the safety case), etc.

It is a basic requirement that the leaching characteristics of the wastes are well known and understood, because all subsequent storage and disposal requirements have to be based on this understanding. If no reliable information is available, it has to be assumed that all element/material constituents might be present in a soluble and geo-chemically mobile form.

Leaching tests for wastes are standardized procedures, but the standards to be used depend very much upon the application and are mostly nationally defined[8] because the applied method has to fit into the waste management scheme. In order to determine the waste class and the appropriate standards for the disposal of these wastes leach tests can be made with distilled water, at high pH values (e.g. at pH=10), or at low pH values (e.g. at pH=4.0). These different methods make sense because

- certain toxic constituents are only mobile under specific conditions,
- certain waste constituents can influence the pH of the leachate (such as concrete pore water or calcium hydroxide), thereby mobilizing or de-mobilizing certain toxic constituents,
- pH values can change with time, e.g. after selective leaching of soluble constituents or by the reaction of Carbon dioxide that inflows with air, mobilizing certain toxic constituents after a longer storage time.

So choosing the appropriate leaching procedure(s) for the expected conditions (storage, disposal, etc.) is a prime matter. In case of the waste streams here, several interactions come into question and all three test methods should be applied. Only these experiments can be used to reliably understand the short- and longer-term leachate characteristics of the wastes to be stored or disposed.

As such characteristics are not available for none of the three waste streams, only a few “generic” assumptions can be made on leachate characteristics. The following generic assumptions can be derived from the mineral composition. For the two wastes rich in gypsum (NUF, FGD) the leachate will be saturated with $CaSO_4$. The

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[8] E.g. for hazardous wastes in Germany the industry standard DIN 38414-S4 defines the standard leaching procedures to be applied. The results for the soluble phase determine the waste’s disposal characteristics and safety class.

phosphate rich stream (WLP) is not expected to leach much of its high phosphate content because of the strong binding to the associated metals and the low solubility of these compounds.

As there is no information available on leachate tests and the waste's pore water characteristics, the trace element content of NUF and FGD, the pH, Eh and neutral/acidic/alkaline leachability etc. no reliable estimate on the environmental characteristics of the leachate in storage and under disposal can be made. It has to be assumed that radio- and chemo toxic constituents are fully soluble and geochemically mobile.

4.1.5 Waste quantities

The amount of wastes generated is given in Table 4.5. Year 1 is listed separately, the quantities in the subsequent years are larger. The waste quantities over the first ten years are summed up in column 4 of the table, over the complete operating time in column 5. Column 5 of the original table in /RWMP 2011/ has the same header as column 4, but the numbers given in that column are exactly 1 * (Quantity Year1) plus 19 * (Quantity in Year2).

Table 4.5: Waste quantities arising in tons, after /RWMP 2011/

	Single years		**Accumulated**	
Waste	**Year 1**	**Year 2 ...**	**Year 1...10**	**Year 1...20**
FGD	29,460	58,920	559,740	1,148,940
NUF	89,910	177,820	1,689,290	3,467,300
WLP	32,000	64,000	608,000	1,248,000
Total	**151,370**	**300,740**	**2,857,030**	**5,864,240**

The table shows that the amounts of wastes are in a relevant quantity range of more than 1 million tons each. This quantity makes it necessary to

- engineer storage and disposal facilities for these wastes on a stable subsoil with low differential settlement,
- isolate the wastes from the environment, given their unknown solubility and migration characteristics,
- plan for a robust waste management solution able to cope with the different economic, social and societal uncertainties that might play a role over the decade-long operations.

4.2 Waste storage on-site

The three waste streams NUF, FGD and WLP are stored on-site in dedicated facilities called "Residue Storage Facilities" (RSF): The following chapters describe the design, the requirements and the estimated performance of those facilities.

4.2.1 Design of the storage facilities

The design of the RSFs is different for the NUF/FGD and the WLP waste stream. Fig. 4.1 shows the principal design of the WLP storage facility.

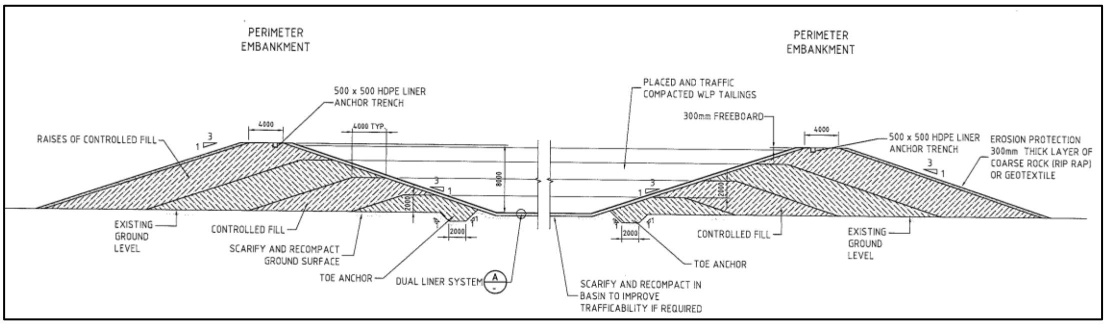

Fig. 4.1: Principal design of the WLP storage facility, taken from /Lynas 2008/

It consists of a surrounding impoundment, built up with raises of controlled fill, and a dual liner system. Fig. 4.2 shows the principal design of the layers of the liner system. On top of the HDPE liner a layer of 400 mm sand is foreseen to protect the liner /RWMP 2011/, not shown here.

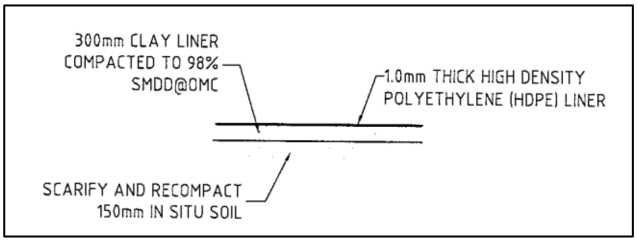

Fig. 4.2: Detail of the principal design of the liner system of the storage facility, taken from /Lynas 2008/

The surface below the facility is made of fill material to achieve a minimum distance of 1 m to the existing groundwater level. The fill should have “low permeability” (no exact requirements and quality assurance procedure provided) and be compacted to reduce settling. Underneath that fill the following natural layers have been identified /WorleyParsons 2008/:

- < 1.8 m depth: Clayey gravelly sand,
- 3.0 m depth, 0.6 to 1.7 m thick: Swamp deposit, silty clay, rich in organic constituents, very soft to soft,
- > 4.2 m depth, 0.2 to < 2.2 m thick: Alluvium, silty clay,
- > 4.2 m depth, 0,3 to < 2.1 m thick: Marine sand,
- > 4.2 m depth: Silty sandy clay.

No conductivity evaluation in the boreholes or pump tests, exact material descriptions and analysis, variability information on layer thicknesses in the different boreholes, etc., were provided.

The construction of the WLP-RSF facility is foreseen in two phases. The final stage is planned for a height of 9 m /RWMP 2011/.

The wastes are poured into that basin as a paste with a moisture content of 30 to 40% /Lynas 2008/. In the design phase air drying of the waste was assumed to achieve a water content of roughly 25% before the waste is put in place and compacted.

Fig. 4.3 provides a view on such a storage facility.

Fig. 4.3: Storage facility, phase I (photo taken October 2012)

The impoundments of the RSF's for the NUF and FGD waste streams are designed differently in that for the latter two RSF, the waste material itself will be used to construct the impoundment. It was planned to let those wastes dry to roughly 5% water content and to staple this dried waste to form the embankment.

4.2.2 Requirements upon a storage facility

Waste classification

No formal requirements are defined for these kinds of interim storage systems. For reasons of groundwater protection and quality no leakage should be accepted, because the disposed wastes, and probably also their leachates,

- have a considerable content of radionuclides (esp. the WLP waste stream),
- have, after the leach process, a still high content of rare earth elements such as La and Nd, considered to be of low to medium toxicity,
- are saturated with gypsum (FGD and NUF), and
- can also contain traces of process chemicals and several environmentally toxic elements.

No internationally recognized waste classification scheme for low radioactive, but long-living waste with chemically considerably hazardous constituents is available. Each country has its own rules or regulates those wastes on a case-by-case basis. The wastes here should be classified as “long-living low radioactive and hazardous wastes”, unless otherwise proven.

Barriers and their quality

The constituent's leaching ability and geochemical mobility are unknown. So the first potential barrier, the waste itself and its solubility characteristic, cannot be evaluated as a fully functional barrier, because it is of an unknown overall quality.

So the liner system as the second potential barrier should be able to enclose the wastes and prevent the leachate from leaving the facility to the subsoil, preventing any further spreading of toxic constituents.

The following layers, a "low permeability" soil underneath the liner system installed to achieve a flat base and the geological layers (see chapter 4.2.1) are not qualified as barriers and their quality as barrier was not proven (missing conductivity testing of the boreholes, missing pump tests, no Q&A for conductivity measurements during installation defined and followed, etc.).

It is common sense that the underground conditions of such a facility have to guarantee that large-area settlement does not differ, in order to protect the barriers integrity. If differential settlement rises, the barrier would crack and lose its integrity.

So the liner system is the only protective measure that has to enclose the waste completely (single barrier system) and has itself to be protected by additional conditions. Having only a single barrier instead of independent multiple barriers is acceptable

- for a limited storage period (e.g. not for long-term disposal),
- if the hazards to be contained are in the "low" range (e.g. unacceptable for short-lived or long-lived medium or high-level waste), and
- if the barrier technically meets the necessary quality standards and is constructed under reliable control conditions (material and construction Q&A, in-situ testing, etc.).

Thus relying only on a single barrier under the above defined conditions is inappropriate and poses an unacceptable risk for man and the environment.

State-of-the-art for liner systems that can be qualified as a barrier

Fig. 4.4 shows the design requirements for disposal facilities for two types of municipal waste as well as for hazardous waste, which are state-of-the-art in Germany. The scheme also demonstrates how these technical standards address the different environmental risks associated with the disposal of the different waste types: the more toxic and mobile the higher the necessary isolation and barrier quality.

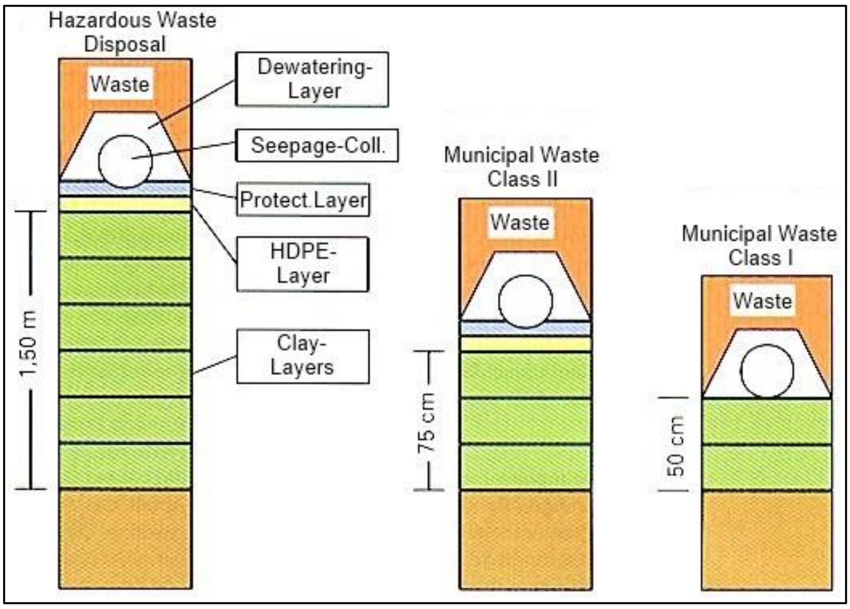

Fig. 4.4: Design requirements for the disposal of different waste classes in Germany after /TASi 1993/, figure modified after /Rüter/

For hazardous wastes and for Class II municipal waste, comparable with the waste streams here, /TASi 1993/ requires a HDPE liner with a minimum thickness of 2.5 mm. The reason behind this requirement is that liners with less thickness do not withstand higher mechanical loads and cannot be installed to the necessary quality (with in-situ checks of the integrity, tests on welding/gluing interfaces, etc.).

The following can be derived from that:

- The minimum layer thickness for the clay liner should be 50 cm. At least two separate layers of 25 cm each should be installed to ensure that the necessary quality requirements are met. For higher-toxicity wastes the number of single 25 cm-layers rises (3 or 6 instead of 2).
- The HDPE liner's minimum thickness is 2.5 mm to ensure that the necessary mechanical stability can be achieved and that the installation on larger areas can be performed with the necessary quality, involving testing of integrity.

If not designed and built in that way, the function of the protective layers cannot be guaranteed to function over the shorter term, nor over the longer term.

4.2.3 Comparision between requirements and RSF design

The basic design of the RSF facilities is such that

- only a single 30 cm clay layer is installed instead of two or more,
- a HDPE liner of only 1 mm thickness is installed instead of the much more robust quality with a thickness of at least 2.5 mm,

- no evidence is provided that the underlying natural soils (swamp layer, sand, silty clay, etc.) are sufficiently mechanically stable and homogenous to avoid deformation caused by the expected differential loads under storage operation conditions.

So the RSF design does not guarantee that this layout even works as designed and planned. Difficulties with achieving a

- flat and mechanically stable fill area underneath to install the clay layer on top of it,
- homogeneous (or even) settling of the subsoil (to avoid cracking of the clay layer and mechanical stretching of the HDPE liner),
- homogeneous clay layer of that small size, and a
- close and tight HDPE liner layer with that thin material

are evident. The result will be that leakage is to be expected from the beginning, even before any waste is in place. This is even more relevant in later phases when the waste is filled in and piled up to 9 m high. The mechanical stress may result in massive damages to the thin HDPE liner and the vulnerable single clay layer, resulting in leakage losses and the spreading of radioactive and hazardous constituents.

The approval of the PEIA /Pahang 2008/

- confirms that this design is sufficient, but doesn't mention any criteria or standards that their confirmation has been based on, and
- does not set appropriate quality assurance requirements for proving the layer's integrity under normal and mechanical stress conditions.

Hence the basic technical design of the facilities is inappropriate and leakage is already predictable and caused by poor design decisions.

This impression - that the design predicts leakage of the facility - is backed by the Preliminary EIA. There, the following is written on leakage:

> *"The potential leaching of trace metals, including radioactive lanthanide metals, from the residues may result in contamination of the underlying soil and groundwater resources. It is noted that there are no groundwater abstraction points or direct groundwater users have been identified on-site or at immediate down-gradient locations. Additionally, there are no other potentially sensitive groundwater receptors within the zone of impact."* /Environ 2008/

This is an astounding finding, because

- the water level in only seven boreholes on the site (see Exhibit 4.17 in /Environ 2008/) was only measured a single time and on one single day,

- the water level and flow direction has to be expected as being very dynamic, given the high precipitation rates and the high permeability of the overlying layers and the conductive geologic layers (see chapter 4.2.1).

The three arrows in Exhibit 4.17 represent the status of groundwater flow on a single day, so it is at least inappropriate to identify down-gradient locations and impact zones from this very limited information, as stated in the PEIA. If more measurements and results exist, or even a complete hydrologic study (which should be one of the basic inputs to conduct a PEIA for a facility, where groundwater is among the potentially affected environmental compartments), those require publication in an updated PEIA. The license conditions in /Pahang 2008/ do not prescribe a complete hydrologic study either, so that reliable flow directions, seasonal transport speed profiles, etc. are unknown at the site und will remain in doubt in the future. So it is not possible to reliably define up-gradient and down-gradient directions, detection delay times, monitoring wells placement, etc.

The Preliminary EIA evaluates the technical measures to prevent leakage (the above described liner system) as adequate and recommends the following measure:

> *"• Monitoring of groundwater quality in the vicinity of the RSF should be conducted on a regular basis. More groundwater monitoring wells should be installed at strategic locations to detect potential groundwater contamination;" /Environ 2008/*

Monitoring is in any case necessary to understand groundwater movement at the site by identifying flow speed, flow directions, seasonal variations, etc., but does not help to prevent leakages. Leakage that leaves the RSF facility would only be detected several months later, in wells close to the source, and only at those monitoring wells that are exactly in the flow direction from the leakage point(s), etc. In the worst case no well is exactly placed and the contamination is not detected. Once detected, no opportunities for stopping further leakage are available. The only mitigation measure left in case of a damage is to pump and treat large amounts of groundwater, because the conductivity of the underlying sand and silty clay layers is very high.

So, the weak design of the RSFs and their below-standard enclosure quality cannot be remedied or healed by monitoring, no matter how close, reliable and complete groundwater monitoring will be.

The license document /Pahang 2008/ just repeats Lynas's layout and formulates no relevant design changes or requirements.

4.2.4 Summary of design evaluation

The design of the RSF facilities is technically inappropriate because it does not prevent leakage. This will allow contaminated liquids to leave the storage basin, to potentially spread toxic and radioactive constituents into the fill underneath the facility and subsequently to enter the natural layers underground and reach the groundwater table at only 1 m distance below ground surface. As the subsoil (mainly sand and swamp material) is highly hydraulically conductive and rainfall in the area is comparatively high (approx. 3,000 mm/a), the travel speed of the groundwater is also high. Thus, any released constituents will spread very rapidly and practically no absorption on subsoil layers for inorganic contaminants is available to limit the contamination spreading in the environment.

Since the base lining system of the RSF is weak by design, the facility will leak. As mitigation would neither be complicated (two layers of 25 cm clay each instead of a single 30 cm layer is not complicated to install) nor expensive (2.5 mm HDPE is available as an industry standard product), avoiding these losses is reasonable. It could well be that a non-compliance with Malaysian regulation has to be considered. The Malaysian regulation requires the following:

> *“Part V Control of radioactive waste generation*
>
> *8. (1) The licensee shall ensure that the generation of radioactive waste and its impact to the environment is as minimum as possible.”* /RWMR 2011/

Keeping the impact to the environment to a minimum would be possible by applying higher technical standards that are state-of-the-art and to a well-engineered quality. The current design is unlikely to ensure that such a required minimization of impacts.

4.3 Operation of the RSF facilities

4.3.1 Capacity issues

The capacity of the RSF facilities is designed to be able to store the generated waste that arises during the first five years of operation, as described in /Environ 2008/.

The limited capacity planned for as a design decision has the following consequences.

For the WLP waste only permanent disposal comes into question (see chapter 4.5.3). So such a disposal facility has to be planned, sited, licensed, constructed and put into operation within five years after the operation of LAMP starts. This is a completely unrealistic schedule, even under the most favorable conditions. Most of the projects of this type require at least 10 years. This can be derived from the long list of steps that have to be performed (see chapter 4.5.6 for details) and also from a similar case in Malaysia (dates were taken from /AELB 2012b/):

- the rare earth factory of the company ARE (Asian Rare Earth) in Bukit Merah was closed in 1992,
- decommissioning of the plant started in May 2003 (11 years after closure),
- the construction of the disposal cell EC-2 of the Long-Term Storage Facility (LTSF) started in 2010 (18 years after closure).

So this example demonstrates that even the 10-years-estimate can extend to 15 to 20 years, especially if unclear framework conditions complicate the process.

Given the fact that Lynas currently is still in the stage of selecting and evaluating different waste management options and that the siting efforts have been continuing over the past five years with no result, the schedule cannot meet the necessary target to remove wastes from the WLP RSF starting from year 6 of operation. The public perception that Lynas as a private company strives for its profits and is not a public entity trying to fulfill a public obligation to protect people, additional to the perception that a foreign and not a domestic company is seeking potential sites, etc., will add to the difficulties in searching for a site where a community is willing to host such a facility.

The possible consequences are that at least one additional RSF facility on the Gebeng site will have to be planned, licensed and put into operation in year 5 from the time of first production at LAMP. If the time schedule slips even further behind, the still unresolved waste management problem will force more and more compromises and unsafe and technically unsound interim solutions.

Issuing an operating license under these conditions starts a machinery that develops its own rules and necessities. Enforcing a finalization of the still unresolved management problem is nearly impossible, given the enormous economic consequences that any delay in production would have.

The IAEA report /IAEA 2011/ found that:

> *“the appropriate authority is authorized to direct the licensee to take any corrective measure to rectify the situation if it appears that adequate facilities are not available for the safe accumulation and disposal of radioactive waste.” /IAEA 2011/*

So, the IAEA is aware that the limited storage capacity in this case might run into trouble. But the IAEA is sure that the appropriate authority (AELB) has instruments to enforce corrective measures, but does not comment on which measures those might be in such a case. This is in contrast to one of the major IAEA safety standards: the prime responsibility for safety resides with the facility’s owner, and that he should apply the defense-in-depth principle to not run into this kind of trouble.

Lynas is already trying to expand the on-site storage capacity:

> *"The RSF facility for storage of the WLP residues is currently designed with the capacity to hold residues from 5 years of operation; however, onsite expansion of the RSF will have sufficient capacity to store all of the WLP residues to be generated during the 20 years operational period for the LAMP."* */Environ 2011/*

The consequences of this plan are discussed in chapter 4.5.4.

4.3.2 Water balance

The following operating mode applies for the RSF that stores the WLP stream. The waste is placed into the WLP-RSF as a paste with a moisture content of around one third. After some evaporation and separation, the waste shall be spread out on top of the storage space. Supernatant liquid[9] shall be pumped from the RSF, collected in a HDPE lined water retention pond and subsequently used in the Water-Leach-Process. No WLP liquid shall be released as effluent /Environ 2008/.

Besides the capacity requirements (1 in 100 year precipitation events) no further details on the layout, technical design and the leachate characteristics of liquids stored in WLP liquid retention pond are available. The Preliminary Environmental Impact Assessment /Environ 2008/ has not discussed the retention ponds as potential sources of impacts for groundwater, even though the concentration of radioactive and toxic constituents in that liquid are essentially the same as the leachate in the RSF storage and so should have been considered a potential source of groundwater contamination.

No quantitative balance is given for this scheme of a "closed cycle". Only a limited amount of water leaves the WLP process towards the further product process. This amount has to be minimized for technical reasons, because the subsequent extraction processes benefit from the high concentrations of REEs in the leachate. Rainfall adds water continuously to the RSFs, increasing its amount, in the RSF and its associated retention pond. Fig. 4.5 shows the long-term average of precipitation in Kuantan, adding up to roughly 3,000 mm per year.

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[9] In the PEIA /Environ 2008/, the RIA /Nuclear Malaysia 2010/ and the IAEA report /IAEA 2011/ the dry density of the WLP waste stream is listed as 0.7 t/m^3. If this would be correct, the water in the stored paste would not settle on top of the wastes but underneath. As the WLP consists mainly of iron phosphate with a density well above gypsum (2.3 t/m^3) this is considered a typing error with repeated copying.

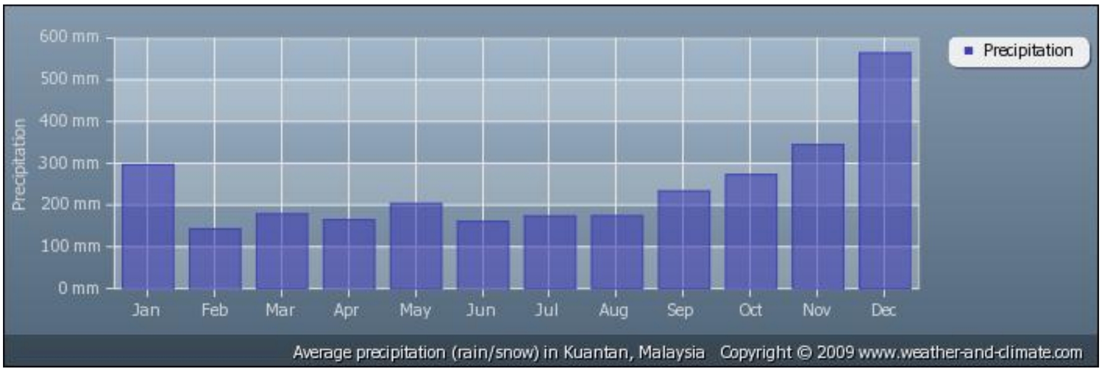

Fig. 4.5: Multiannual average of precipitation in Kuantan/Malaysia, taken from http://weather-and-climate.com

A rough estimate of the water balance for the WLP-RSF in Tab. 4.5 demonstrates that the water inflow from precipitation is roughly 10 times larger than the waste paste's water content. With this high amount of precipitation the precipitation-evaporation balance is in any case positive in Malaysia. So the amount of water in this "closed cycle" will be continuously rising, if no back feeding into the process is possible.

Table 4.6: Estimate of the water balance for the RSF-WLP

Inflow Source	Parameter	Conditions	Value
Waste	Volume	Fully operational	91,600 m³/a
	Water content	Minimum in Paste	30%
	Water inflow	Inflow with Waste	**27,480 m³/a**
Precipitation/ Evaporation	RSF Area	Complete area	48 ha
	WLP-RSF Area	Per facility	16 ha
	Catchment area	Minus embankment, etc.	80%
	Catchment area	Net	128,000 m²
	Precipitation		3,000 mm/a
	Inflow		384,000 m³/a
	Evaporation rate	Estimate	30%
	Inflow-Evaporation		**268,800 m³/a**

The re-use of water pumped off of the WLP-RSF and fed back into the leaching process cannot be easily balanced because only partial descriptions are given:

- Exhibit 2.2 states an hourly rate of 506 tph as inflow to the cracking and leaching process /Environ 2008/,
- the text in /Environ 2008/ on p. 2-15 states that the complete water demand of the LAMP facility will be between 330 m³/hr and 550 m³/hr under steady state conditions.

The above estimated yearly inflow (average precipitation assumed) accounts for roughly 34 m^3/hr under steady state conditions. In case of the following conditions the water balance rate can change drastically so that WLP water might be in excess:

- production stoppages over longer times can happen for several reasons (insufficient raw material or chemicals supply, outages for repair and maintenance, accidents, etc.),
- above-average precipitation,
- failure of pipes and pumps to handle water,
- etc.

For any of the above cases it is necessary to plan for a robust water management to avoid any unintended overflow with adverse environmental consequences.

4.3.3 Emplacement management

In /RWMP 2011/ the following modification to rainfall management is discussed:

> *"During heavy rainfall and in particular the monsoonal wet season the surface of the residue is expected to become wet, soft and slippery making placement of residue during this period problematic due to the poor trafficability of the residue surface. Therefore a temporary cover may be required to keep the area of active residue placement dry during the wet season. A potential solution to this problem is to size the drying shed with sufficient capacity so residue can be stockpiled during the wet season awaiting placement in the RSF during drier weather."*

No further details are given on how the "temporary cover" during heavy rainfall and the monsoon season works or will be installed and removed. As during the times the "temporary cover" is in place the emplacement of wastes is interrupted (the monsoon season lasts three months) another storage stockpile is necessary. The associated doses for workers are not included in the radiological assessment /Nuclear Malaysia 2010/.

For this modification of storage management again no balances are provided. As only the "emplacement area" is foreseen to be covered, the complete water balance is not influenced relevantly by this measure. The part of the surface that is actually not covered can soak liquid again, after having dried out before, and cannot be accessed throughout the wet season, which means that emplacement is not possible over very long time periods.

In the three months from November to January only roughly 40% of the total precipitation can be avoided, so it mainly depends on the operating conditions of the "temporary cover" during the rest of year how much of the rainfall can be avoided.

4.3.4 Conclusions

The following conclusions can be drawn from that:

- The WLP-RSF retention pond has not been considered as a potential contamination source for groundwater. Its layout and safety characteristics are not described.
- As there is no complete and conservative water balance for the storage- and leaching process provided, there is no proof that the “closed-cycle” design of the leaching-/storage process will work as designed.
- If under certain circumstances the water balance is positive (precipitation exceeds water requirements for the leach process) leachate will accumulate and it can be necessary to discharge insufficiently treated leachate to avoid overtopping of the RSF or its associated retention pond. To avoid this, a robust water balance, based on conservative assumptions (e.g. longest demand reduction, largest yearly precipitation, lowest surface evaporation rate), is necessary.
- The water management procedures for heavy rain events and for the monsoon season are not described and the discussed mitigation measures are technically unsound. It cannot be excluded that the paste does not dry and access to the RSF for the emplacement of waste will be impossible over longer time periods than currently expected. No sound technical concept for managing the wastes during the period of inaccessibility of the RSF surface is presented. Elevated radiological doses for that stage have not been calculated and included in the radiological assessment.

4.4 Other wastes from the operation of the facility

For a part of other wastes from the operation it is foreseen that they will also be emplaced into the RSF facility, if those are also radioactive. In the Preliminary EIA /Environ 2008/ the following is said about wastes from maintenance/repair and from the exchange of filters:

> *“Waste refractory from kiln maintenance (which will be generated at an estimated 5 - 50 tons every two years) and filter cloths from filtration processes (estimated at 5 - 50 tons per annum) may exhibit low levels of radioactivity and will be disposed of at the RSF.” /Environ 2008/*

The following demonstrates that the expectation that these wastes might exhibit “low levels of radioactivity” is a serious underestimation of the risk associated with these wastes.

4.4.1 The effect of scale enrichment

In facilities that process naturally occurring radioactive materials the effect of enrichment of scale on surfaces is a well-known phenomenon. Scale enrichment occurs in uranium ore milling, in phosphate production and in the oil and gas industry. The effect includes the following:

- On certain surfaces such as pipes, valves, filter clothes, etc. certain elements of the decay chain (such as radium) enrich. These “concretions” build up an insoluble, firmly adhering layer (e.g. of radium sulfate) and accumulate with time. The amount of accumulation depends on the separation efficiency, which can be very low to very high, and is practically unpredictable.
- Once trapped in the concretion, the nuclide specific decay chain of the separated element builds up and the gamma dose rate rises.

4.4.2 Example calculation for scale buildup

In order to assess the possible consequences of scale buildup for the waste management, an example is calculated here. In selecting the parameters, realistic rather than exaggerated conditions were assumed.

The assumption is that around 1% of the radium, as contained in the ore, separates on a small part of the surfaces in the cracking and separation stage of the facility (on the inner surface of a pipe or on a filter cloth) over only one year of operation. For the nuclide chain buildup it is assumed that it lasts another year without further accumulation. The resulting composition is listed in Table 4.7.

Table 4.7: Example estimate for scale composition of Ra-228 after over one year of operation, followed by one year of decay product buildup

Ore concentrate, 1 yr	65,000	tons
Ore concentrate	5.71	MBq/t
Scale enrichment share	1	% of total
Decay time	1	yr
Composition	**Nuclide**	**Bq**
	Ra-228	3.29E+09
	Ac-228	3.29E+09
	Th-228	1.06E+09
	Ra-224	1.05E+09
	Rn-220	1.05E+09
	Po-216	1.05E+09
	Pb-212	1.04E+09
	Bi-212	1.04E+09
	Po-212	6.69E+08
	Tl-208	3.75E+08

The table shows that the buildup of the chain nuclides after one year has only reached one third of the maximum value, for longer operational periods the buildup is larger.

4.4.3 Doses from scale-bearing wastes

The following dose rates would result from that scale, assuming that the small area of accumulation is viewed as a point source[10].

The dose rate under unshielded conditions assumes a pure radium sulfate layer (see layer composition in the annex). The self-shielded condition assumed calcium sulfate. Co-precipitation assumed 463 µg radium sulfate together with one gram of ordinary gypsum. To assess doses under realistic work conditions, a shielding layer of steel (outside of a pipe with accumulation inside) and behind a layer with 10 cm concrete (as an analogue for a layer with WLP gypsum) was calculated, too. For comparison purposes the dose rate for a worker's time limit of 8 hours per year is also displayed.

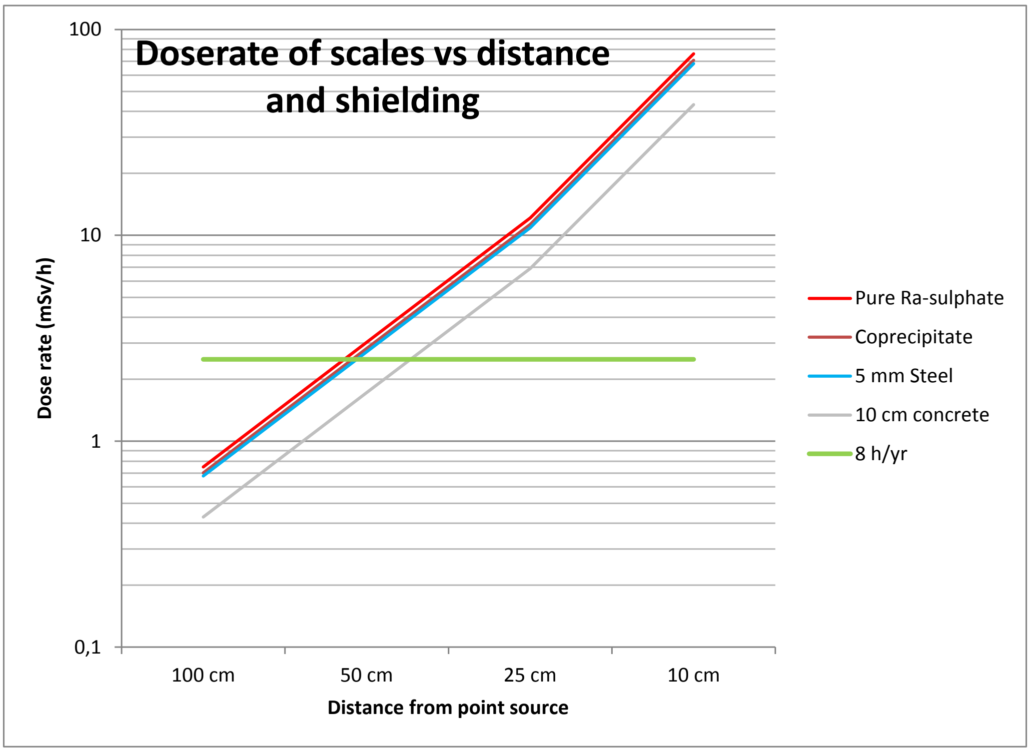

Fig. 4.6: Dose rate of the accumulated scale for various distances and shielding conditions

Dose rates at very short distances, usually during direct manual handling of filter cloth and repair/replacement/cleaning work on pipes, can be well above 10 mSv/h,

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[10] Calculations were performed with the Java Calculator at http://www.wise-uranium.org/rdcx.html, following a plausibility and quality check; see annex for composition documentation.

requiring extremely short access times of only few hours or even less than one hour per year until permissible worker's doses of 20 mSv/a are reached. At larger distances, e.g. in one meter, the dose rate of roughly 0.5 mSv/h is still high, compared to the dose rate of the ore concentrate where the contamination stems from (around 0.003 mSv/h).

The shielding effect of 5 mm Fe/Cr/Ni standard steel, e.g. the dose rate inside versus outside of a pipe, is comparatively small and requires equally limiting the exposure time. Concrete shielding of 10 cm thickness is more effective, but doses are still high.

4.4.4 Radiological consequences of scale enrichment

In the diagram, a dose of 2.5 mSv/h indicates work under extreme radiologic conditions, because within a duration of 8 hours (one workday, e.g. repair work) the maximum yearly dose of 20 mSv/a for a worker can be received. In that case, remote handling has to be considered to limit collective worker doses.

If a dose of 1 mSv/a for a worker is seen as a trigger value for

- increased health monitoring of the workers,
- protective measures, with a strict radiological control scheme for work planning, and
- strict access limitations and controls for areas where this dose might be exceeded under normal working procedures,

point sources such as scale require thorough and careful consideration. For the emplacement of such wastes (filter cloth, pipes and other equipment) on the RSF either strict radiation protection measures are necessary or the emplacement should not be allowed and another storage location with heavily shielded and access-protected conditions should be selected. As the RSF is seen as a temporary storage, the removal of wastes from this facility should also be taken into account, because those buried wastes are expected to be handled again.

The strong decline of the dose rates with the distance to the point source means that doses are relevant for workers that are working in close proximity to these points. Neither workers outside the separation plant or the RSF nor the general public are affected. The accumulated scale is generally immobile, so releases to air and water pathways are not to be expected. With one exception: if failed equipment is to be shipped outside for repair or cleaning work, the resulting doses for uninformed and unmonitored persons working in repair shops or those who transport those parts might be seriously elevated. Wastes from these operations at repair shops as well as the re-use of any equipment (e.g. including metal melting) can deliver doses far above all accepted protective limits and risk levels. If those materials find their way outside the facility unacceptable risks can be posed, including to the general public.

The non-consideration of this problem will result in the risk not being taken into account, making it more plausible to arise with no redress or mitigation strategy.

In case of radium the radioactive decay of Ra-228 reduces the risk after very long storage times. So controls over and isolation of those wastes to allow for decay is necessary over at least several decades, before these wastes can be released to the public domain. This estimate on the release practice has to be verified because Ra-228 from the Th-232 decay chain is associated with smaller concentrations of Ra-226 from the U-238 decay chain (see Fig. 3.4) in the LAMP case. Ra-226 has a much longer half-life time, so it has to be made sure that its contribution does not raise regulatory concerns.

It should be noted that the scale enrichment estimate was performed with realistic and even with some assumptions that might be too low, so possibly underestimating dose consequences. If scale enrichment takes place over longer times (e.g. in case of pipes operated over the whole lifetime of the facility, involving higher enrichment shares than only 1% and longer buildup of the decay chain over ten years) than assumed here, the received doses can even be higher than calculated.

4.4.5 Evaluation and conclusions

The expectation that “only slightly radioactive parts” have to be handled and emplaced into the RSF facility in the EIA is a serious underestimation. This underestimation is continued in the Radiological Impact Assessment /Bangi Ray 2011/. Even though it might be the most relevant source for radioactive doses for workers in the plant, no mention is given to this effect nor are worker doses estimated or assessed under these conditions.

These deficiencies lead to the following conclusions:

- Neither Lynas (that accepted the EIA and the RIA and forwarded those to the authorities) nor the authors of these two basic assessments were aware of those serious effects.
- If the operator of the facility is not aware of the effect in advance,
  - the necessary close monitoring of specific points in the facility that are especially prone to accumulate scale is not planned or implemented and scale enrichment will only be detected by chance during routine scanning,
  - the necessary precaution in handling and storing those parts is not taken,
  - the necessary procedures for radiologic control and risk avoidance are not implemented or followed,
  - the necessary tools for monitoring, handling and control are not in place when needed.
- The authorities are well aware of the effect and the associated potential risks found in the oil and gas industry /AELB 2009/. No hints were found in any of the

available documents that the authorities have rejected the EIA or the RIA as inadequate or incomplete nor have they set appropriate conditions for the prevention and limitation of those risks in the Lynas facility.

4.5 Long-term management of wastes

Even though the LAMP facility has been in planning for over a decade now, has been granted a temporary operating license and will soon commence production, the long-term management of the associated wastes is still unclear. The following chapters discuss and evaluate the different options proposed, assess their technical feasibility and acceptability and formulate appropriate recommendations.

4.5.1 Management options discussed

Interim RSF storage and external long-term isolation disposal

Within the planning stage the characteristic of the RSF facilities has been changed, and the final setup is unclear. According to older sources, the RSF facilities were only designed as storage - the waste was to be removed. The Preliminary Environmental Impact Assessment stated in 2008 that:

> *“All residue streams and the filter cakes will be stored onsite within the engineered Residue Storage Facility (RSF) until a suitable permanent disposal option is selected by Lynas in conjunction with the AELB.” /Environ 2008/*

In its Radioactive Waste Management Plan /RWMP 2011/ the following is stated:

> *“Upon plant closure after 20 years, any remaining residue within the RSF will be transported off site to a permanent disposal facility (PDF) for long term storage. At the time of report preparation (December 2011), the proposed site for the PDF had not been identified.” /RWMP 2011/*

Interim RSF storage, release from regulatory control and re-use

The Radiological Impact Assessment /Nuclear Malaysia 2010/, the Radioactive Waste Management Plan /RWMP 2011/ and /IAEA 2011/ all recommend the re-use of the waste streams. The discussed re-use opportunities include

- use of the NUF and FGD waste stream as fertilizer, as gypsum-rich raw material for the production of plasterboards, etc.,
- use of the WLP waste stream as building material, after mixing it either with gypsum, concrete or magnesium oxide.

Interim RSF storage, exportation to outside Malaysia

This management option was, according to the media, discussed by Lynas.

> *“Lynas, which has faced community opposition in Australia and Malaysia, and continuing legal action, said it intended to go beyond the conditions of its approval and "remove from Malaysia the radioactive tailings material that is the principal cause of the community anxiety by engaging with export markets for the processed co-products from the [plant]".” /Canberra Times 2012/*

Lynas has filed such an application at the Australian Radiation Protection and Nuclear Safety Agency on March 30, 2012 /Ludwig 2012/. No license has been granted yet.

That option seems to have been also discussed with the licensing authority /MalaysiaKini 2012/, but was not set as a license requirement in the Temporary Operating License.

Interim RSF storage, conversion of the RSF to a final disposal facility

This option is discussed in the Environmental Impact Assessment /Environ 2008/:

> *“As part of the fill/construct methodology for the RSF, cells will be capped once design capacity is achieved creating a landform with positive drainage. Capping is envisaged to comprise a 500 mm thick rock-fill layer to serve as a capillary break, overlain by low permeability clayey soil and topsoil to lower the risk of infiltration. Interaction between rainfall and surface water runoff from capped cells and permanently stored residues will be minimised and the final site topography will encourage surface water to drain off-site to prevent ponding and standing water.” /Environ 2008/*

This option was also presented to the IAEA:

> *“The review team was informed by Lynas that the RSF will be designed to meet stringent requirements such that, if necessary, it could become a permanent disposal facility.” /IAEA 2011/*

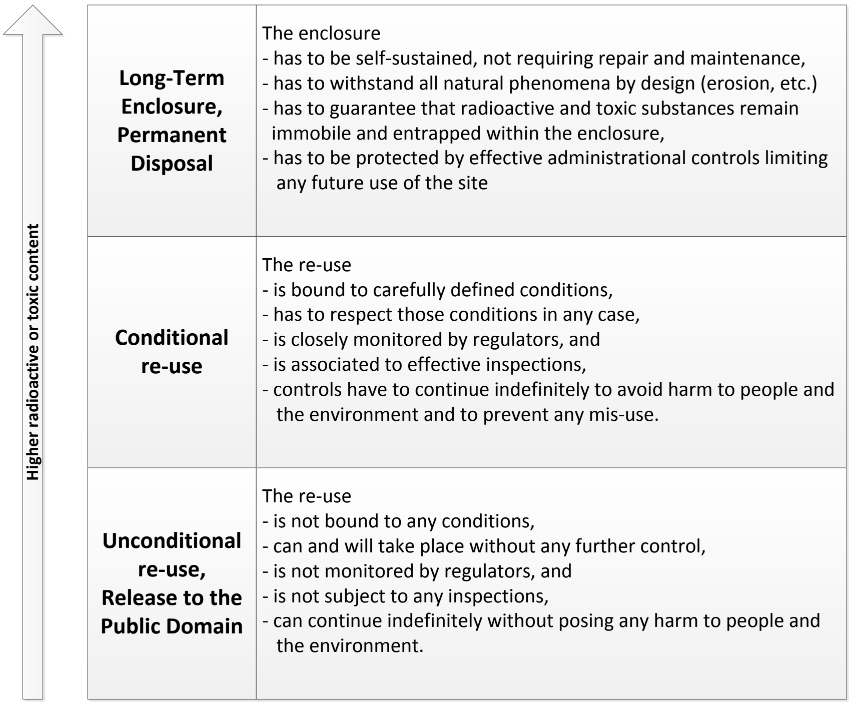
What is meant here by the term “if necessary” can only be speculated on. The IAEA has not rejected the idea of mixing the requirements for short-term storage over 25 years with the long-term requirements for protected enclosure over indefinite periods.

4.5.2 Requirements for selecting waste management options

For waste materials that contain radioactive or toxic constituents three basic options are available. The following scheme (Fig. 4.7) characterizes these three options.

Each of these three options requires a specific approach. The permanent disposal option

- requires a thorough site selection with respect to long-term stability (flooding, geological conditions, meteorological conditions, etc.),
- has to be designed in a manner taking any future conditions and their changes into account,
- has to consider the radioactive and toxic inventory and its properties (such as geochemical mobility) to derive the necessary quality and longevity of barriers,
- requires effective regulatory controls to guarantee that the facility is built as designed,
- has to establish and traditionalize limitations on land use.



Long-Term Enclosure, Permanent Disposal	The enclosure - has to be self-sustained, not requiring repair and maintenance, - has to withstand all natural phenomena by design (erosion, etc.) - has to guarantee that radioactive and toxic substances remain immobile and entrapped within the enclosure, - has to be protected by effective administrational controls limiting any future use of the site
Conditional re-use	The re-use - is bound to carefully defined conditions, - has to respect those conditions in any case, - is closely monitored by regulators, and - is associated to effective inspections, - controls have to continue indefinitely to avoid harm to people and the environment and to prevent any mis-use.
Unconditional re-use, Release to the Public Domain	The re-use - is not bound to any conditions, - can and will take place without any further control, - is not monitored by regulators, and - is not subject to any inspections, - can continue indefinitely without posing any harm to people and the environment.

Fig. 4.7: Management options for materials with radioactive or toxic constituents

Unconditional re-use

- has to establish robust limiting concentrations for the radioactive and toxic content of the materials released, also taking limitations of knowledge into account,
- has to ensure that new knowledge is incorporated dynamically to make sure that robustness is not yet exhausted,

- has to guarantee by effective control measures that released materials meet those limits in all events.

It should be noted that the decision to release a waste material to the public domain is in most cases irreversible or can only be reversed with immense effort, should it emerge that it is no longer desirable. So the pre-cautionary principle should govern this process.

Conditional re-use is a solution that requires

- continued and effective regulatory control over the materials, including material balances, accounting, marking, inspecting, etc.,
- additional human resources on part of the users and regulators,
- reliable mechanisms to guarantee that it works.

As this option is very prone to failures, hence very risky, and very seldom works over the long term and only in a few cases in the real world, is it not considered an option from here on.

Very often an unclear mixture between these three scenarios is used in radiation dose calculations, without stating that clearly. For the calculation, a certain use of the material is assumed. The circumstances of exactly and only this single use are derived and may appear appropriate at first sight (e.g. to yield a 50 hours exposure time per year, by a factor of 175 smaller than 8,760 hours for the whole year). This practice leads to low doses being estimated, even though the re-use in the next use-cycle of the material (e.g. recycling and use as built material) may be under very different circumstances and over much longer exposure times. A conditional re-use (in exactly the form assumed) mutates to an un-conditional re-use, because there is no control that the material enters a different after-use in one of the following cycles. For long-living nuclides as well as for toxic metals in a waste this “shortsighted analysis” is inappropriate and risky.

4.5.3 The waste streams from a radiological perspective

In order to check whether any unconditional release from regulatory control comes into question, a typical use scenario for the three waste streams WLP, NUF and FGD was defined and the gamma dose rates to be expected were calculated. For thorium-rich wastes the gamma dose rate is the sensitive parameter, other pathways such as radon and ingestion do not play an important role.

The resulting dose rates are a major criterion if the wastes can be released from regulatory control and can enter the public domain and then be used for any reasonable purpose. This has to be assumed because

- if no strict regulation and control system is effective, no control over whatever re-use is available and reliable any more,

- the half-life of the radioactive constituents exceeds any time that a certain selected application would last, so whatever specific application is foreseen for the prime use period, there will be subsequent uses of that material that aren't under any further control and are unlimited in scope,
- if certain limitations for the use of the material in the prime use cycle might be known and respected, the knowledge about these limitations gets lost with time, so that in the second or third use cycle the awareness might not be available any more.

So the most sensitive applications have to be selected to assess if the materials can principally be released from further regulatory control.

The model scenarios include

- an unconditional release of the NUF and FGD waste, assumed to be used as a 20 cm thick material for wall or floor construction application,
- unconditional release for the WLP waste stream and assuming undiluted use of a 20 cm thick material in a wall or floor application, alternatively a 2.5 cm thick material (e.g. as a wallboard), as well as producing a 50/50 and a 1/100 mix with (uncontaminated) gypsum.

For all applications an area of 16 m² is assumed, e.g. as a 4-by-4 m wide wall or floor or an equivalent. Material compositions were calculated from the mineral composition analysis (see Table 4.1, Table 4.3 and Table 4.4, /RWMP 2011/) and nuclide content from /Nuclear Malaysia 2010/. The calculations were performed with the Java calculator tool at

http://www.wise-uranium.org/rdcx.html?src=v&shn=0[11].

Input parameters are documented in the annex. It should be noted that only the thorium decay chain was calculated, uranium decay chain nuclides were neglected for simplicity.

The resulting dose rates at different distances to the material are shown in Fig. 4.8. For comparison purposes only the dose rate for a whole year at a De-Minimis-level (10 µSv/a) is listed as “BRC” (Below Regulatory Concern).

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[11] After checking plausibility and quality of the tool.

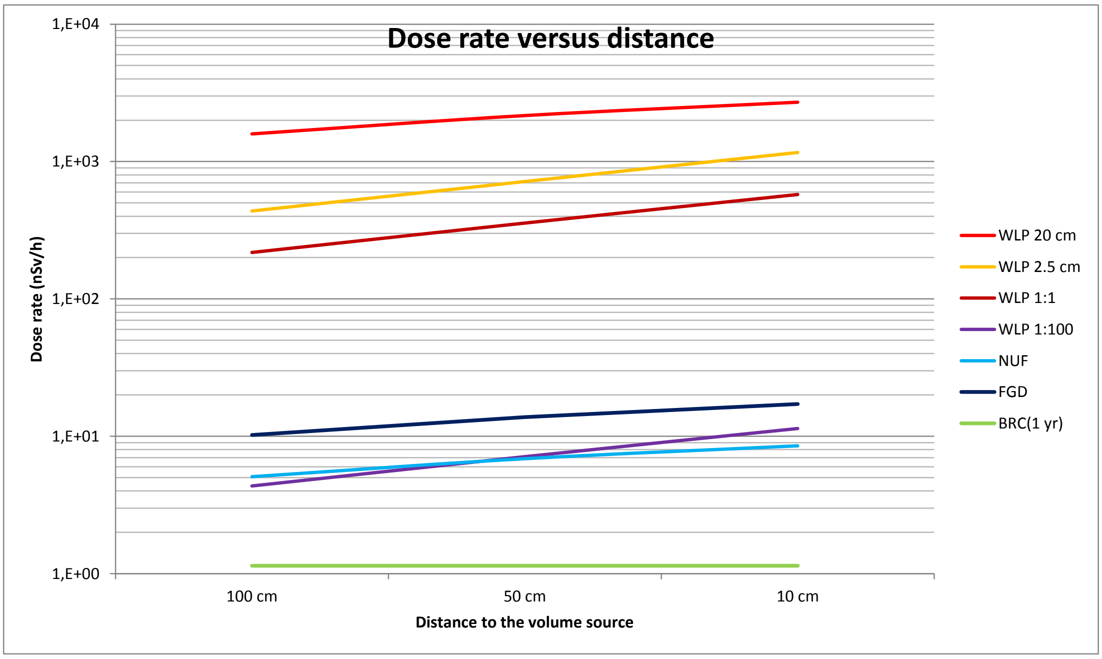

Fig. 4.8: Dose rates from the waste streams in nSv/h

It can be seen from the diagram that the dose rates

- of the WLP waste and the WLP-gypsum mix 1:1 are roughly two orders of magnitude higher than for NUF,
- require a dilution factor of 1:100 to bring the WLP down to those of the NUF wastes,
- differ between the 20 cm thick layer and the 2.5 cm thick layer by only a factor of two, and not 8 as to be expected,
- in the different distances (10 to 100 cm from the source) differ only by a factor of roughly two, because the assumed extension of 16 m² is nearly causing maximum rates and enlarging this area has no relevant effect any more,
- the dose rates for all waste streams are between a factor of 5 (NUF), 10 (FGD) and 1500 (WLP) above the BRC level.

Fig. 4.9 shows the doses resulting from these dose rates. Exposure times are selected for the complete year (8,760 hours) because this case cannot be excluded when release of the material to the public domain is assumed.

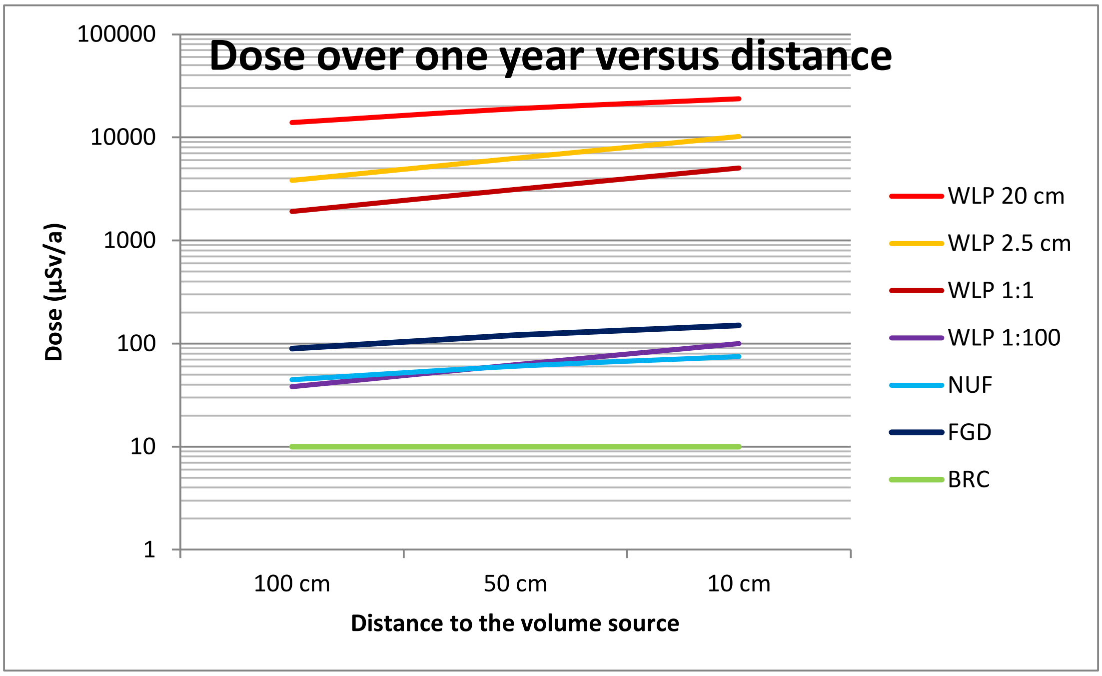

Fig. 4.9: Doses from the waste streams over one year versus distance

The doses associated with WLP waste re-use are above the regulatory concern level (BRC) by a factor of more than 1,000, the doses for the mixture with gypsum 1:1 by a factor of 200. Even the usual limit for controlled emissions from nuclear facilities (1.000 µSv/a, see Table 3.2) is exceeded by the WLP waste stream and the 1:1 mixture. So even if other mixtures are used or assumed (e.g. 10:90), the doses from WLP re-use remain well above the accepted risk level for the release of radioactive material to the public domain.

To dilute the material by mixing it with even larger amounts of uncontaminated wastes is not a technically viable option. It would require dilution rates in the order of 1:500, requiring the handling of more than 300,000 tons of material per year of full production. This is technically by far unrealistic. The dilution option reduces individual doses to below regulatory concern, but has also health implications: the number of exposed individuals rises with the same factor that the single individual’s dose is reduced. So the sum of individual risks, the resulting collective dose and the associated health damages remains essentially the same - an effect that excludes excessive dilution of WLP waste as a possible management option.

The NUF and the FGD waste are by a factor of roughly 10 and up to 15 above regulatory concern. If a dilution of roughly 1:10 with uncontaminated material is applied, these two waste streams can principally be recycled from a radiological perspective (assumed that technical issues such as homogeneity, material properties resulting from construction standards and their by-product content are within acceptable limits). As the required dilution factor is small, collective dose effects are not prohibitive.

The consequence of this is:

- The WLP waste stream should in no case be released to the public domain and re-used, even if mixed with smaller or larger amounts of other materials. Disposal and permanent enclosure in a designated disposal facility is the only viable option for this waste stream.
- The NUF and FGD waste streams can be re-used from the purely radiological point of view, because the associated radiological risk is small, but any re-use has to carefully consider their toxic content (NUF: 1.5% Oxalate, 1.5% $LaPO_4$; FGD: MgF_2; both: trace content of process chemicals and trace metals) and have to be evaluated against applicable standards (e.g. for building material).

Hence, the management options for NUF and FGD waste need to be assessed and evaluated further, taking their by-product content and their usability into account. For WLP waste, the permanent disposal option has to be considered the only remaining option.

This result of the calculation is in direct contradiction to Lynas's and the regulator's claims that the waste might possibly be recyclable and reusable. Lynas has not performed any dose calculations for this reuse in its Radioactive Waste Management Plan /RWMP 2011/, even though this would be the correct place to perform these and a strict requirement for any reuse scenario. This demonstrates that Lynas is not familiar with common radiation protection standards. As an example for this argument, the following citation demonstrates the respective confusion over this crucial point:

> *"I also believe that PDF is not the preferred option as mechanism for managing radioactive wastes for long-term management of radioactive wastes. I found that LYNAS had presented its Radioactives Waste Management Plan (RWMP) stating that the waste produced at its LAMP operation would be included as waste in the waste streams to be recycled into by-products with commercial value for a variety of uses. The term "waste" is not important at this stage because it simply means an end-product or product to be disposed of only after all the processes of recycling and reusing the by-products are done. This is consistent with Part VI of the Regulations of the Atomic Energy Licensing (Radioactive Waste Management) 2011 which required that recycling and reusing processes are fully tested before any radioactive materials are declared as disposable radioactive wastes." /MOSTI 2012/*

The terms "dose" or "dose limits" and "health" or "health risk" isn't even mentioned in that text. To define the reuse the highest priority and to not even mention the associated risks and the public health requirements is not in line with any internationally accepted protection standards. Any reuse has strictly to be linked to the risk posed and the doses associated with that reuse. Regulators such as MOSTI, that miss or ignore that basic requirement do not fulfill their obligations and are unacceptable.

4.5.4 Option “Permanent disposal on the Gebeng site”

One of the discussed options is to leave the WLP waste in the RSF, to cap this storage facility and change it to a permanent disposal site.

Barriers and their quality and reliability

The safety features necessary for the permanent disposal of very long-lived wastes requires at least one, preferably more than one, reliable barrier. The barrier(s) have to be able to enclose the radioactive and hazardous material over a very long time. Barriers can be

- the waste itself: if the waste is geo-chemically inert, even if in excessive contact with water, and if this property is not altered over the long term, this can be termed as a reliable barrier against future leaching processes,
- cover layers: if the cover layers are able to prevent the entry of precipitation or to minimize it, and if they are able to prevent any access to the disposed material, the cover layers can be considered a reliable barrier; layout of the cover has to be self-sustained, taking long-term erosion, degradation and other natural conditions into account,
- base layers: if the base layers (liners) are able to prevent mobile contamination from leaving the disposal facility by absorption, they can be considered as barrier; note that the base layers cannot counterbalance poor design or failure of cover layers,
- geologic base layers: these build the base for the long-term stability and integrity of the engineered facility and can contribute to reduce the mobility of leakage leaving the disposal cell.

Note that the long-term reliability of engineered barriers (cover and base layers) can only be designed to withstand degradations for a limited time, e.g. for 1,000 years (US standard for uranium mine and mill tailings), so these barriers can only be considered reliable over this period of time, simply because the state-of-the-art of engineering is limited.

“Engineering” of the waste properties to withstand leaching processes is possible, but is in most cases very limited due to the large variety of components. “Shortsighted” mixtures of the waste with soluble or reactive material such as MgO or $Ca(OH)_2$ to reduce leaching has no barrier quality due to their limited effect in the long term.

The geologic barrier can only be influenced during the site selection process. To select and optimize this barrier requires comprehensive knowledge and understanding of the site specific conditions.

Note that all barriers are not independent from the others, so that a disposal facility has to be seen as a system of interdependent structures and requires optimization. Missing natural barriers, for example, cannot be simply engineered. A single barrier is not appropriate for long-term disposal.

Barrier quality and reliability at the Gebeng site

The Gebeng site was chosen for its favorable conditions for constructing and operating an industrial plant, the LAMP. It was not chosen as a site for the permanent disposal of thorium and chemically contaminated waste. The site has the following adverse properties that make it not recommendable for such a facility:

- The waste's long-term leaching properties are unknown.
- The base liner is not designed to deliver reliable mobility reduction over the long-term. The HDPE liner does not prevent leakage (see chapter 4.2) and the narrow clay liner does not withstand long-term degradation and uneven settlement.
- No details are known about the design, the material properties and the quality assurance measures during installation of the engineered fill underneath the base liners. The short distance to the water table of less than or equal to one meter does not add any capacity for absorbing or delaying soluble radioactive or toxic leachate.
- The large swamp layer at short distances to the base of the RSF does not provide the necessary stability to reduce the settling characteristics of the large and heavy RSF facility to an acceptable steady state within two or three decades after closure. The function and performance of the engineered barriers of the facility is in doubt.
- In case of a rising water table or during serious flooding events, the base layer of the facility can be reached. The site lacks the necessary quality of the geologic barrier.
- Sand, swamp layer and other highly water conductive layers underneath its base causes elevated mobility for solutes. These layers cannot be considered a barrier with the necessary reliability and quality.

If selected independently from the plant's site and in a site selection procedure that includes other potential host sites, this site would never have been selected.

Even if, by design modifications, stability of the subsoil as well as high quality emplacement of the clay layer and tightness of the HDPE-Liner might be achieved and proven during construction, it should be noted that the presented concept does not allow for more than an interim storage of the envisaged waste streams, pending provisions for a final solution. Thus, if constructed as designed, it should be made very clear that the RSF facility's safety function is limited in time, that it is insufficient for a permanent disposal and that plans are to be presented and provisions (financial, organizational, technical) are to be made to demonstrate and ensure a safe and reliable final disposal solution for the stored materials.

This applies to the currently already constructed and existing RSFs as well as to any future extensions on the Gebeng site, that are currently under discussion to relieve the potential capacity bottleneck (see chapter 4.3.1).

4.5.5 Option "Waste return to the country of origin"

This option should be completely ruled out. The waste is generated as a paste with more than 30% pore liquid. Transportation of such material over large distances, packaging, safe handling and the complete logistic (including import and export licenses) are not manageable. The option is unrealistic.

If it is correct that Lynas has offered this option to the regulator, this should trigger an evaluation of whether the operator has the necessary reliability to operate a facility where radioactive material is handled. The Atomic Energy Act /AELA 1984/ has no provisions that require the license holder to demonstrate its reliability, and it holds no provisions in the case that a licensee fails to meet the necessary reliability. This should be considered a serious gap in the Malaysian regulation.

The regulator recently stated the following:

> *"Concerning the Nineth Ground of Appeal of the Applicants, I know that the AELB had demanded a guarantee letter from LYNAS to ship out all residues or wastes to the country of origin if they cannot be converted into commercial products as intended and this condition is clearly stated as a condition of the TOL." /MOSTI 2012/*

This, again, demonstrates the confusion that the regulator is responsible for. As the WLP waste cannot be converted into a commercially marketed product for health and safety reasons (see analysis above), he will have to ship the waste produced under the TOL in any case to the country of origin. If the country of origin, in this case Australia, refuses to accept this and the operator, in this case Lynas, has guaranteed that, because the regulator (in this case AELB on behalf of Malaysia) required that, an unresolvable situation arises because Lynas can neither fulfill the requirement without breaching Australian law nor fulfill the TOL requirement. Unresolvable situations like that, where different requirements contradict each other, are to a high degree a risk for the general public, because they usually end with a safety compromise that allow solutions that would be, under normal circumstances, not acceptable.

4.5.6 Option “Permanent Disposal Facility at a different selected site”

This is the only safe option left for the long term management of the WLP waste stream, because an upgrade for the RSF at the Gebeng site will not meet the isolation requirements and the waste cannot be released to the public domain.

Regulatory requirements

In its reply to an appeal to terminate the TOL the regulator stated the following:

> *“12.1 Concerning the first ground of appeal of the Applicants, I do sincerely believe and declare that there is no obligation by law for LYNAS to present its final Permanent Disposal Facility (PDF) location, plan or design before the TOL is granted by AELB.” /MOSTI 2012/*

From a legal standpoint, this might be correct, but many questions can be raised from that:

- Is a PDF required by law at all?
- At which stage of the formal process will an operational PDF be formally required?
- When is a PDF required? (Prior to the first ore concentrate import, prior to any test operation with ore concentrate, at startup of the operation, after the first five years of waste generation, after the complete waste is generated, twenty years after the waste has been completely generated?)

No answers to these questions has so far come to our attention, these seem to be open questions.

The MOSTI statement above raises the question if the legal requirements are appropriate enough to regulate and control facilities such as the Lynas refinery plant. Or else, in absence of appropriate regulation, if this kind of facility simply cannot and should not be operated because the regulatory system is not able to provide enough control over the associated hazards. Facilities generating toxic or radioactive waste require appropriate regulation to limit the associated risks, especially those which arise from the long-term hazards that those wastes are associated with.

Leaving the appropriateness of the regulatory and control system open and allowing the operation of a facility, that generates wastes which

- cannot be released from regulatory control without unacceptably large damages for health and the environment,
- require reliable long-term isolation from men and the environment over virtually unlimited times,

leads to an unacceptable situation.

As, in absence of appropriate controls, the environmental consequences are unacceptably large, already the Environmental Impact Assessment EIA process would have to identify and quantify those consequences and has to propose means to reduce, limit or completely avoid those consequences. If those environmental consequences cannot be reduced or limited to an acceptable level or completely avoided, or if the necessary means cannot be achieved, e.g. because no community in Malaysia is explicitly willing to accept such a PDF on their grounds, the project simply cannot be continued, because one of the integral parts of the facility doesn't function properly. So, if there is "no law requiring Lynas to present its PDF", as MOSTI stated, is the law on Environmental Impact Assessments in Malaysia appropriate enough to regulate facilities generating thorium contaminated wastes?

The EIS was, without setting those clear requirements, finally approved in 2008 /Pahang 2008/. The TOL was issued in 2012, requiring the following:

> *"3) The plan and location of the PDF have to be submitted and approved in a period not later than 10 (ten) months from the issuance of the Temporary Operating License." /AELB 2012a/*

No detail is available on

- the expected site selection process to be applied,
- the criteria for selecting sites,
- the criteria to be applied to such a facility,
- the approval process,
- the process to achieve consent with the stakeholders,
- etc.

It should be noticed that according to this TOL license requirement only the plan and location has to be submitted and approved. So the TOL does not require the PDF to be factually working before any wastes are produced. So the regulators decision remains completely open, when and under which conditions the PDF will finally be required.

Lately the ability of the operator to plan and design such a PDF has been generally questioned by the Ministry of Science, Technology and Innovation. In the context of an appeal to terminate the TOL, the Ministry stated:

> *"I sincerely believe that the Chemical Characteristic for the residue or waste has to be ascertained first in order to be able to determine the design of a specific and final PDF." /MOSTI 2012/*

This is not understandable, because

- the WLP waste composition is well known and well within rather small uncertainties,
- the chemical composition of the waste does not differ widely from gypsum that is generated from other technical processes,
- the water content of the wastes can well be technically adjusted to achieve a dry product that can be easily disposed,
- solubility properties of the wastes, relevant for long-term leaching and settling processes, can easily be measured with small amounts of that waste, as they are typically available from small-scale pilot plants.

If MOSTI's statement would be correct,

- no environmental impact assessment could be made,
- no RSF planning and design performed, and
- simply no start of operation of the facility could be allowed because basic data on relevant properties of a large mass product would be missing.

Anything would be completely open, and the requirement of the IAEA expert group (see below), requiring the design of the PDF as pre-requisite for an operating license, is so declared to be impossible by MOSTI. Further, MOSTI even increases the confusion in stating:

> *"In addition, I repeat everything I had said in paragraphs 12.1 to 12.7 above and stressed that it is hard to produce a Comprehensive Long Term Plan for Waste Management because at this stage LYNAS has yet to produce any residues or wastes." /MOSTI 2012/*

That factually says that science and technology, the division that MOSTI is responsible for, is "nearly blind" until all the waste mass has been made, with no solution in mind and with no precautions to avoid adverse consequences. With that ignorance against modern science and technology and ignoring all knowledge on what is well known in chemistry, radiology and technology, the confusion is on its maximum.

Setting up strict safety requirements for the process of establishing a PDF would make clear what has to be expected from the applicant. As this is already the second case for such a facility type, with the LTSF in the Bukit Merah case being the first, there should be enough experience to draft such regulatory requirements. The serious delays in this first process (see chapter 4.3.1) and the necessity for long-term hazard control should be reason enough to immediately establish those requirements.

Prerequisites for establishing the option

To establish such a long-term disposal option in the Lynas case it is required to

- develop a (non-site-specific or “generic”) safety case for such a facility,
- establish sound site selection criteria, based on the required safety features,
- identify, explore and evaluate different sites,
- select the most suitable site(s) as candidates,
- establish consent with
  - the landowners,
  - the affected local public, engaged preferably in a referendum,
  - the communities involved,
  - the local and regional authorities,
  - the AELB on the national level

  for at least one of the selected sites,
- develop the design, the technical plans, the environmental impact assessment, etc.,
- perform a site specific safety case, and finally to
- apply for a license.

As the Temporary Operation License expects at least the performance of the first four steps in this scheme within 10 month after issuing this temporary license, this is a rather ambitious timetable. An interpretation would be that the AELB anticipates those steps to be performed with a very low performance and quality, as it is simply impossible to select a site without a thorough investigation into the site’s specific characteristics.

Only if the steps listed above are all completely and successfully performed, can the option be evaluated as “available” and “realistic”.

Generic Safety Case for a PDF

Currently the majority of the steps listed above have not been performed and finalized. In IAEA’s radiological review /IAEA 2011/ the performance of even the first step, the “generic” safety case for the external disposal facility, was set as a recommendation. This was seen as a prerequisite to be performed before the start of any operation of the LAMP facility:

> *“The AELB should require Lynas to submit, before the start of operations, a plan setting out its intended approach to the long term waste management, in particular of the water leach purification (WLP) solids after closure of the plant, together with a safety case in support of such a plan.”* /IAEA 2011/

The IAEA then lists six issues that such a safety case should address:

> *“(a) Future land use (determined in consultation with stakeholders);*

> *(b) The dose criterion for protection of the public;*
>
> *(c) The time frame for the assessment;*
>
> *(d) Safety functions (e.g. containment, isolation, retardation);*
>
> *(e) The methodology for identification and selection of scenarios;*
>
> *(f) Any necessary measures for active and/or passive institutional control.”*
>
> */IAEA 2011/*

The “Safety Case”, prepared shortly after, see /Environ 2011/, is in large parts a compilation of generic information, provides no added value on several crucial points that were already identified earlier and so thus lacks the necessary quality to be expected of such a document. To name a few deficiencies:

- The waste as a barrier: Instead of measuring real leachate compositions of real waste samples, the Safety Case lists only generic information on thorium mobility. This is inappropriate, because
  - the chemical composition of the waste is unusual, and is not comparable to the laboratory chemicals usually used to determine solubility,
  - the waste consists of a large variety of components that can influence complexation and other chemical reactions,
  - only real waste samples provide enough reliable information to qualify the waste itself as a barrier.
- Absorption as a barrier function: No site-specific information is given. As this is not possible because no site has been selected yet, only generic information is listed. The cited literature for half of the Periodic System of Chemical Elements is complete, but rather useless because most of the chemical elements listed ignore the K_D concept completely and behave very differently if certain pH and Eh conditions are given or if certain anions (e.g. certain silicates) or complexing agents are available (such as humic and fulvic acids in the swamp layer underneath the RSF). So the listed information is largely useless as long as the specific geo-chemical conditions of a real site are (necessarily) unknown and a state-of-the-art geochemical modeling of the mobility is therefore impossible.
- Hazard and risk evaluation: Comparing waste constituents (by element) with average concentrations in earth (page 26) provides no useful information. It only demonstrates that basic principles of health and risk evaluation are not clearly understood. As natural concentrations of certain elements (e.g. such as arsenic) can cause serious damages to health and can only be considered safe if they do not migrate to groundwater that is subsequently used as drinking water, average soil concentrations do not provide a useful scale for health risk evaluation.
- The term Safety Case was in large parts of the document only interpreted as “Radiological Safety Case”, ignoring all the safety-related issues from non-

radioactive constituents of the waste. This misinterpretation of the term Safety Case results from the close orientation to IAEA's request for such a safety case, as IAEA's mandate (and expertise) as defined by the United Nations (UN) covers only and is limited to radioactive waste issues /IAEA 1956/. This is inappropriate in the Lynas case, where non-radiological hazards play a significant role.

The "Safety Case" provided does not meet the quality standards that are required of such a document. It only provides arguments that support the perception that such a disposal site would be safe. It neither discusses the risks associated with such a facility nor does it provide reliable information on which safety features will be realized with which quality assurance levels to achieve the safety claim for the PDF.

The document should be rejected by the regulating agencies responsible for radiological and environmental issues, together with a complete list of identified deficiencies.

Incomplete compliance with the requirements

The "Safety Case" demonstrates additionally how a requirement can be interpreted in a manner that leads to the direct opposite of what was intended by the agency. IAEA's requirement of the examination of future land use options (/IAEA 2011/, cited above, p. 84) has specified that future uses of the site have to be developed in consultations with land owners and stakeholders. The fact that IAEA has made this requirement number one of its list also places a clear priority expectation on this step. This articulates a clear perception that Lynas will first hold consultations with these groups and individuals.

/Environ 2011/ instead states:

> *"Consultation with stakeholders regarding future uses of the LAMP/RSF or the PDF has not been performed." /Environ 2011/*

Instead /Environ 2011/ provides a theoretical list of general future land use options. This demonstrates that neither the requirement as such nor the necessary priority has been understood by Lynas.

In its final appraisal /Environ 2011/ states:

> *"The modern engineering design for disposal of WLP residues and radiological waste arising from the future decommissioning plan of LAMP in the proposed PDF is based upon the fundamental safety principle of protecting people and the environment from ionizing radiation by containing and isolating the wastes from biosphere. The confidence of the safety case for the recommended PDF is increased upon: Selection of a site meeting the characteristic identified as*

> *the siting criteria, the design and construction of multiple, independent barriers (leachate collection system, synthetic liner, natural low permeability soil barriers, and surficial rock cover) to isolate the wastes from the environment at the PDF; and, reliance upon institutional controls to manage future land use to protect the PDF." /Environ 2011/*

Assuming this characterization to be correct, the necessity to identify and negotiate a site for this facility seems to have no priority for Lynas as it is not even mentioned in its appraisal.

Given the extremely short timetable to perform all these steps and to finally construct such a facility and to get it into the operational stage (five years, see chapter 4.3.1), the ability to establish this option as "available" and "realistic" is more than doubtful. As long as the option is not "available" and "realistic", one of the major prerequisites for issuing an operating license is not given and waste generation cannot be started without shifting undue burdens to future generations.

This risk of shifting undue burdens to future generations will even escalate if Lynas is allowed to expand its storage capacity on the Gebeng site, in order to construct additional RSF capacity on that site and to expand to beyond the 5-year-capacity limit. This would increase the unresolved waste issue, because Lynas would also be relieved from developing a long-term strategy. It then would be possible to accumulate the wastes during the whole operating time over 20 years at the Gebeng site and only then to look at long-term options (e.g. alternative sites for a PDF).

Naming this option in the Safety Case /Environ 2011/, while stating in the following sentence that consulting talks with the relevant local stakeholders (including those at the Gebeng site) have not been performed, is a substantial proof of unwillingness to follow IAEA's recommendations.

4.6 Decommissioning

4.6.1 Requirements

Facilities that contain radioactive or chemically toxic substances require precautions to prevent from adverse conditions should the owner not be available, able or willing to perform the necessary decommissioning and cleanup steps, once the operating time of the facility is over. So it is necessary to establish independent funds covering the necessary steps of decommissioning of the facility and to finalize any necessary waste management steps, including cleanup of the areas and the closure of the disposal facilities.

"Independent" means that the funds have to be managed carefully (given the financial risks) and separated from the owner's assets (so that the funds are available even in case of bankruptcy) as well as from governmental assets (to be available when needed). As some of the necessary waste management steps require timeframes far beyond the operation of the facility, the set-aside funds have to be based on detailed technical plans and economic estimates. If underestimated, part of the necessary expenses are not adequately covered, leading to serious delays in the performance of necessary work and potential failures in preventing and limiting exposures resulting in adverse health and safety consequences.

Funding schemes necessarily have to be dynamic because they must reflect the changing conditions with time. On one side "overfunding" has to be avoided in order not to place undue burdens on the operator, on the other side "underfunding" has to be avoided. In most cases in the past the second was the case.

The necessary funding scheme, considering the accumulated waste amount ("Waste generated"), its disposal ("Waste disposed") and the necessary funds is indicated in Fig. 4.10.

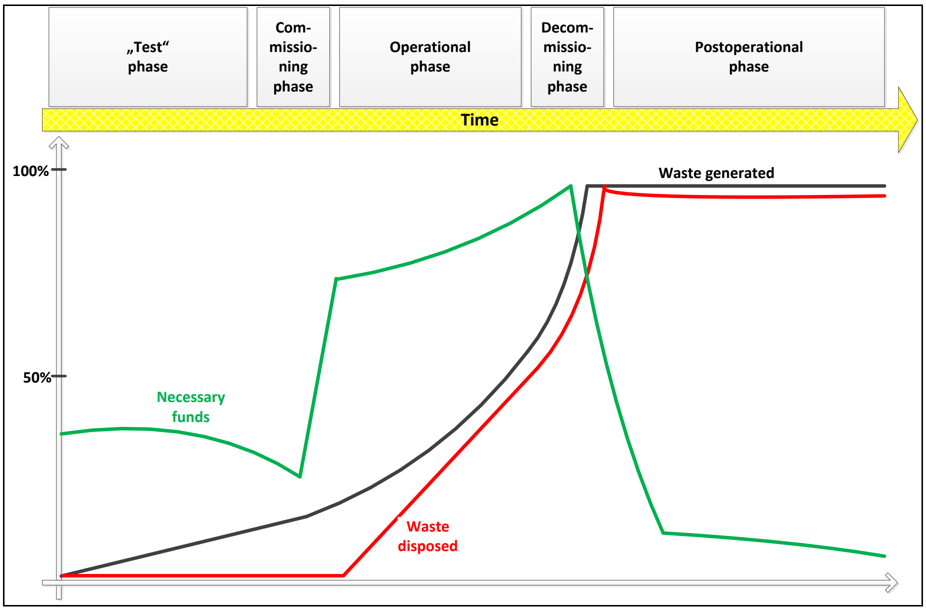

Fig. 4.10: Necessary funds and their dynamics for the different phases

The following can be concluded:

- Most of the necessary funds have to be set aside in the commissioning phase, because most of the cost factors are independent from the waste generated (fixed costs).
- The operational phase only adds small amounts (variable costs).
- In the post-operational phase only small amounts are necessary to cover the costs for remaining activities (e.g. post-operational monitoring).

The latter is only correct, if the disposal design is reliably self-sustained. If a disposal design is selected that requires ongoing repair and maintenance in that phase, the funds to be set aside for this long phase can easily be the major cost factor.

4.6.2 Evaluation

In the IAEA review /IAEA 2011/ no establishment of such regulation and practice was found and the experts recommended to create such a fund:

> *"5. The AELB should implement a mechanism for establishing a fund for covering the cost of the long term management of waste including decommissioning and remediation. The AELB should require Lynas to make the necessary financial provision. The financial provision should be regularly monitored and managed in a transparent manner." /IAEA 2011/*

The Temporary Operating License establishes such funds:

> *"4) Lynas has to provide financial guarantees on the terms as set out under the relevant laws as agreed upon by Lynas (M) Sdn. Bhd a sum of USD 50 Millions be paid to the Government of Malaysia by installments. This is subject to review by the AELB where applicable;" /AELB 2012/*

No information is available on the fund's basic scheme (calculation scheme, parameters, etc.), on the review principles applied, the fund's financial management (independent from the Governments financial assets and to be paid back in case of final performance of the complete work), on the fund's publication (IAEA: "in a transparent manner"). Instead of resolving IAEA's recommendation, the regulator states:

> *"I also stressed that there is no obligations by law to impose this financial bon and fixed amount as a condition under section 18 of the Act 304. Therefore, the amount imposed on LYNAS is purely at the discretion of the AELB." /MOSTI 2012/*

In other words:

- the regulator has no legal base for the funds,
- he is not willing or able to establish such a legal base,
- he has to establish this on a case-by-case basis,
- he is completely depending from the applicants willingness to pay the fund, and
- IAEA's transparency requirement for the fund management is not taken for serious at all.

Typical is how the decommissioning of the facility is looked at. The license document states:

> *“67. A detailed closure plan (abandonment plan) including restoration work, site clearing, soil stabilization, tree planting, landscaping, ground cover plants or whatever appropriate steps recommended should obtain the approval from the Atomic Energy Licensing Board (AELB) and a copy submitted to the Pahang State Department of Environment Pahang not later than six (6) months before the project is expected to be stopped or abandoned.” /Pahang 2008/*

On a basis, that is only established six month before the end of the operational period, no reliable fund for that decommissioning can be established. Today, the continuous establishing, updating and approval of closure plans would be the standard. In order just to know what has to be done later on, to avoid adverse pre-decisions and to be able to operate a facility with the necessary caution.

A legal, reliable and sustainable concept of fund establishment would be very different, but will not be established.

Considering that the construction of the Bukit Merah LTSF, in its size much smaller than the PDF of Lynas, is estimated to cost roughly 100 million US-$ /NYT 2011/, the required installments of 50 million US-$ in this case do not seem to be based on a systematic cost analysis and a reliable funding scheme.

Lynas has however agreed to establish that fund.

4.6.3 Conclusions on funding

The applied method of funding for the long term management of decommissioning costs, including those for cleanup and disposal, is not transparent and does not meet international standards which require it to be well managed, transparent and comprehensive. The funding, as required, should cover the complete costs of those necessary future operations, once the operation starts.

The government of Malaysia should establish a sound and well-defined funding system, to be applied to facilities where later decommissioning, cleanup and disposal operation is vital to guarantee public health and safety in the long term.

5 Summary of the report

The Australian company Lynas plans to import ore concentrate from its Mt. Weld mine in Australia to Malaysia and to process this concentrate in its Lynas Advanced Materials Plant (LAMP) in Kuantan/Malaysia. Lynas has constructed part of the facility and has been issued a temporary operating license (TOL) by the responsible state agencies.

Oeko-Institute was commissioned by the Malaysian non-governmental organisation "Save Malaysia Stop Lynas" (SMSL) to evaluate the emissions from this plant via air and water, the safety issues as well as the waste management in respect to their environmental consequences.

Emissions of radon over the stack

The ore concentrate has a considerable thorium content. Accumulated radon in the ore concentrate is released in the cracking stage of the facility when the ore matrix is decomposed. Radon cannot be filtered and therefore causes air emissions and subsequent radiological exposures in the vicinity of the plant. The dose calculations were reviewed and several minor inconsistencies were found, as well as missing documentation. The reviewed dose results can be summarized as follows:

- The environmental consequences from the emission of radon over the cracking facility's stack are small.
- Even when introducing more strict assumptions in the dose calculation the associated dose and risk remains negligible.
- Small risks should be communicated as such. They should not be compared with natural background levels, because the natural background risk level is not zero and is not always below acceptable levels, based on given current knowledge and understanding. Such comparisons are in most cases unscientific and misleading.

Emissions of sulfuric acid and dust over the stack

In the cracking stage of the facility the ore concentrate is heated with concentrated sulfuric acid. The resulting gas stream passes a waste gas treatment system to remove sulfuric acid mist and other acidic substances as well as dust and then is discharged over stacks. In another part of the facility, separated rare earth oxalate is roasted in a furnace oven. Waste gas from this process is not filtered for dust removal and is discharged directly to the air.

The analysis and comparisons of these emissions shows that

- no reasons are given for the decision to operate the calcination stage without a waste gas treatment system, while other similar examples show that at least a simple dust removal method should be used,
- the static Malaysian environmental regulation in respect to air quality is inappropriate, because it neither reflects improved knowledge on adverse toxicological effects nor does it encourage to the application of improved technical capabilities to reduce emissions; the regulation should be improved by adopting dynamic limits taking advantage of technical improvements,
- the treatment systems of Lynas for abating emissions of acidic gases and acids as well as for dust are neither state-of-the-art nor best-available-technology and causes sulfuric acid emissions that are too high by a factor of at least two and PM_{10} dust emissions that are too high by an even larger factor.

Discharges via the water pathway

The Lynas facility uses water in the cracking stage to dissolve the rare earth compounds. Rare earth elements are stripped from that water solution, the water is neutralized, sludges are removed, the water is collected in a pond, mixes with precipitate and stormwater, and, after monitoring measures, discharged to an earthen channel that transports the wastewater over three kilometers to river Balok, where it is further diluted and finally flows to the South China Sea.

The following conclusions can be drawn from the critical evaluation of the discharges via the water pathway:

- The documents, including the Preliminary Environmental Impact Study, do not provide information on the by-product content of the ore concentrate. No balance calculations can be made for other toxic constituents of the ore.
- The analysis of process water prior to its treatment considers only those constituents which are mentioned in the Malaysian Water Quality requirements for effluents, and even omits analysis of some of the constituents listed there without naming reasons for that omission.
- Specific constituents of the wastewater of the LAMP facility such as rare earth elements and salt are not even mentioned, their concentrations are not calculated and the environmental consequences are not identified, discussed and evaluated, as would be required in a Preliminary Environmental Impact Study.
- A detailed calculation of the salt content of process water was performed and it is shown that the salt content (mainly calcium chloride) is only slightly below that of average seawater and by a factor of at least 15 higher than water that can be used for irrigation. The salt is not removed in the water treatment stages and will be discharged completely.
- The transport of the discharged water with toxic constituents, a frequently high chemical oxygen demand and high salinity in an open earth channel, accessible

by humans and animals, is unacceptable. Water of this low quality should be transported in a pipeline that does not allow seepage to escape to the groundwater and prevent unintended water use.

- The already high chemical oxygen demand of Sungai Balok should not be further increased by allowing additional COD discharge, the approach should rather be to improve overall water quality by removing or reducing the other sources.

Hazards and their control in the production process

The facility stores and handles large amounts of concentrated acids. This is associated with the potential risk that tanks will leak. Rapid detection, preventive measures and the ability to limit the consequences for the environment are necessary. The plant further uses chemicals that are flammable; the possible consequences of fires have to be assessed.

The analysis and the potential consequences of specific hazards posed by the plant to the environment

- have not been adequately assessed (tank spill control measures), so that unacceptable consequences for soil and groundwater would result, or
- have not been taken into account (sulfuric acid vapor release, fire extinguishing liquid loss), so that their potential consequences have not been assessed.

Wastes from the production process

The facility produces large amounts of three different waste types. In the cracking stage the insoluble part of the ore concentrate, together with radioactive thorium, form the WLP waste. The second waste type produced stems from the acid removal from the offgas in the cracking stage, mainly consisting of gypsum with several by-products and is called FGD waste. The third waste type is the condensed sludge from the neutralization stage called NUF waste, also mainly consisting of gypsum with by-products. The wastes are stored in separate storage facilities on the site.

The following conclusions are derived from a detailed analysis of the waste management issues of the LAMP facility:

- The design of the Residue Storage Facilities (RSF) is not state-of-the-art with respect to leakage prevention. A state-of-the-art design would use 2.5 mm HDPE and at least two 25 cm layers of clay instead of 1 mm HDPE and only a single 30 cm layer of clay. The inappropriate layout will result in leakage of radioactive and toxic constituents to the near groundwater even under normal operating conditions. As the layers underneath the facility are not qualified as barriers and do not guarantee the enclosure of those constituents, the spreading of the constituents is not substantially reduced or delayed. It is an open question whether this inappropriate design is compatible with the minimization requirement established in the Malaysian regulation for the control of radioactive waste and its storage.

- The RSF for the waste from the Water Leach Purification (WLP) process stage with the highest radionuclide and toxic content
  - is, due to its limited capacity, not designed to store the wastes produced before a safe external permanent disposal facility has been established. This will put undue pressure on the sensitive process of careful site selection for the permanent disposal facility, resulting in a possible reduction in the quality and transparency of the site selection process as well as the regulatory process. The capacity bottleneck will result in unplanned measures becoming necessary at the LAMP, performed with reduced quality or as sub-standard solution.
  - is inadequately designed to safeguard against heavy rain and the monsoon season. Storing the waste in the RSF requires a certain drying period prior to emplacement. This natural drying process is unlikely to work in periods of heavy rain and high humidity. To develop appropriate alternative procedures requires the establishment of additional technical steps and this will inevitably increase the dose for workers who have to handle those wastes. This additional exposure has not been accounted for in the Radiological Impact Assessment (RIA).
  - has not been designed to cope with enhanced scale enrichment of radium within the WLP stage of the facility and its associated waste category with a much more intense radiation level to be stored in the RSF. No procedure has been prepared for these wastes. The high potential for substantially higher doses for workers and the associated risks have not been recognized and planned for.
  - should not be designated as a permanent disposal facility, because basic site suitability criteria, facility design and the long term isolation potential of the facilities are significantly deficient. Their insufficient base layers cannot be upgraded to meet the more stringent and time-resilient requirements of a permanent radioactive waste disposal site.
- The option of releasing WLP wastes to the public domain, either in its original form or in a mixture with other diluting substances such as concrete or fixing agents, would lead to excessive exposure of radioactive doses to individuals and to the general public via direct gamma radiation, posing a health hazard further afield. This option poses an unacceptable risk to the general public and should be banned and ruled out completely.
- A safe and publicly acceptable way to establish a permanent disposal facility (PDF) for the WLP waste must be seen as a prerequisite for the management of these wastes. This includes a complete and comprehensive safety case, sound and approved site selection and suitability evaluation criteria, the broad consent

of the affected public and a carefully checked construction license for such a PDF. The expectation in the Temporary Operating License (TOL) for the LAMP facility that this process could be performed within only 10 months with the necessary quality, transparency, durability, reliability and the successful completion of the necessary consultation processes is highly unrealistic and risky. In fact, this 10 months period has now lapsed since the TOL was approved on the 30th of January 2012, yet a permanent site for the PDF has not been identified. The fact that LAMP can only continue its operation if such a PDF is able to dispose of the initial wastes produced in the first five years of the waste generation process should be evaluated as a strong condition to bind the issuance of a license for LAMP to that construction license for the PDF. No waste generation should be allowed until the necessary steps to establish such a facility have been performed to the required safety standards and until this management option has been finally established.

- The current approach towards ensuring that the necessary funds for facility decommissioning, cleanup and waste isolation are in place and secured is neither state-of-the-art nor reliable and transparent. The government of Malaysia should establish a sound and well-defined funding system, to be applied to facilities where later decommissioning, cleanup and disposal operation is vital to guarantee for public health and safety in the long term. As long as this is not established with the necessary standard and transparency, the operation of those facilities should not be allowed in order not to place undue burdens on future generations.

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6 Attachments

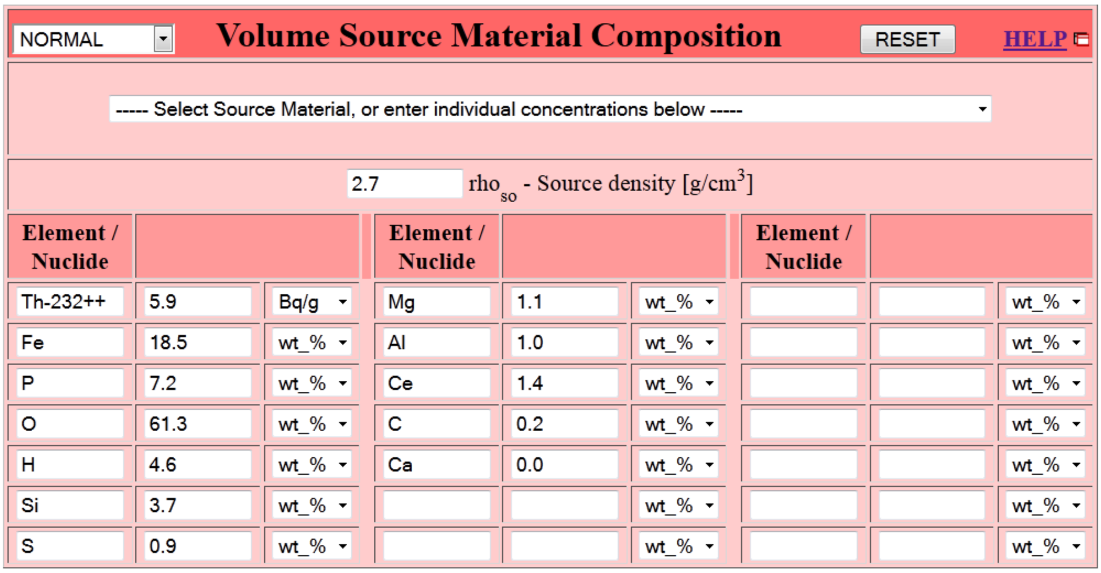
Abbreviations

Table 6.1: Abbreviations used in the text

Short	Meaning	Short	Meaning
AELB	Atomic Energy Licensing Board of Malaysia	ARE	Asian Rare Earth (operator of the Bukit Merah plant)
BRC	Below radiological concern	COD	Chemical Oxygen Demand (of wastewater)
Deodymium (Didymium)	Praseodym-Neodym	EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement	FGD	Flue Gas Desulfurization
GLC	Ground Level Concentration	HRE	Heavy rare earth elements
IAEA	International Atomic Energy Agency	ICRP	International Commission on Radiological Protection
LAMP	Lynas Advanced Materials Plant	LC	Lanthanum-Cerium
LD_{50}	Lethal dose (for 50% of the exposed individuals)	LCPN	Lanthanum-Cerium-Praseodymium-Neodymium
LNT	Linear-no-threshold theorem	LTSF	Long term storage facility
NGO	Non-Governmental Organization	NORM	Naturally Occurring Radioactive Material
NUF	Neutralization Underflow stage	PDF	Permanent disposal facility
PEIA	Preliminary Environmental Impact Assessment	PM	Particulate Matter (“dust”)
REE	Rare Earth Element(s)	REO	Rare Earth Oxide
RIA	Radiological Impact Assessment	RSF	Residue storage facility
RWMP	Radioactive Waste Management Plan	SEG	Samarium-Europium-Gadolinium
SMSL	NGO “Save Malaysia, Stop Lynas”	SS	Suspended Solids (in water)
TAC	Total activity concentration	TENORM	Technically Enhanced NORM (enriched content)
tpa	tons per annum, metric tons per year	UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization	WLP	Water Leach and Purification

Documentation of input parameters for dose rate calculations

WLP waste stream

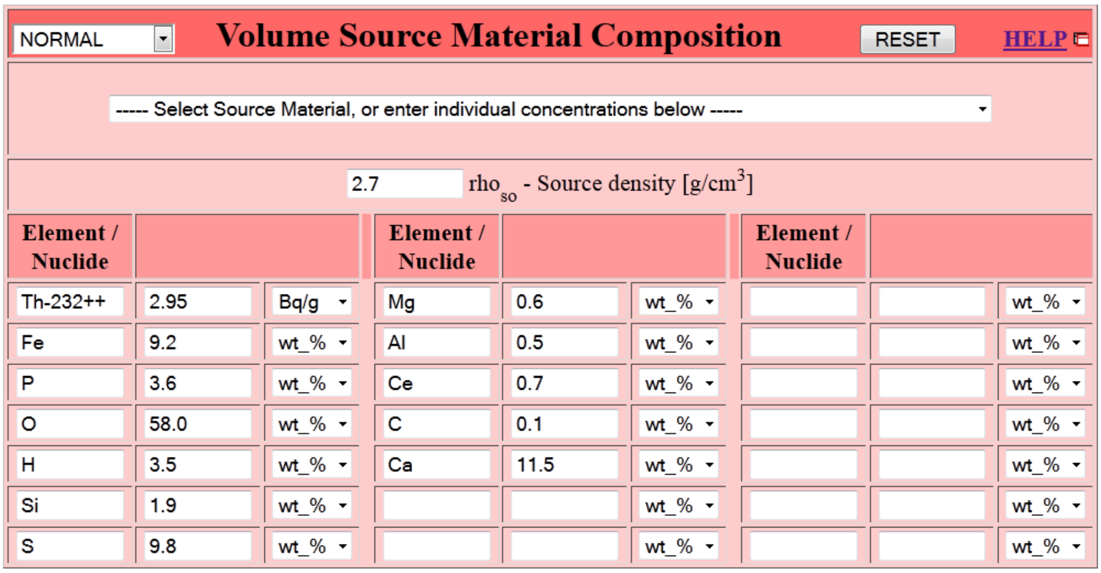


2.7 rho$_{so}$ - Source density [g/cm^3]

Element / Nuclide			Element / Nuclide			Element / Nuclide		
Th-232++	5.9	Bq/g	Mg	1.1	wt_%			wt_%
Fe	18.5	wt_%	Al	1.0	wt_%			wt_%
P	7.2	wt_%	Ce	1.4	wt_%			wt_%
O	61.3	wt_%	C	0.2	wt_%			wt_%
H	4.6	wt_%	Ca	0.0	wt_%			wt_%
Si	3.7	wt_%			wt_%			wt_%
S	0.9	wt_%			wt_%			wt_%

Fig. 6.1: Input parameters of the dose calculation for the WLP waste stream

WLP waste mixed 1:1 with gypsum

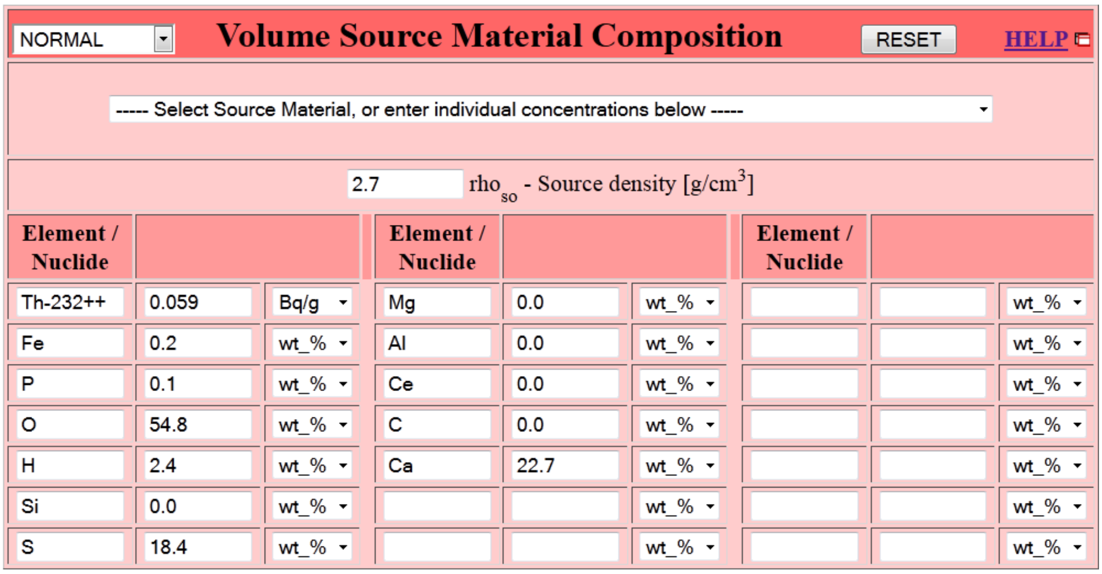


2.7 rho$_{so}$ - Source density [g/cm^3]

Element / Nuclide			Element / Nuclide			Element / Nuclide		
Th-232++	2.95	Bq/g	Mg	0.6	wt_%			wt_%
Fe	9.2	wt_%	Al	0.5	wt_%			wt_%
P	3.6	wt_%	Ce	0.7	wt_%			wt_%
O	58.0	wt_%	C	0.1	wt_%			wt_%
H	3.5	wt_%	Ca	11.5	wt_%			wt_%
Si	1.9	wt_%			wt_%			wt_%
S	9.8	wt_%			wt_%			wt_%

Fig. 6.2: Input parameters of the dose calculation for the WLP waste mixed 1:1 with gypsum

WLP waste mixed 1:100 with gypsum

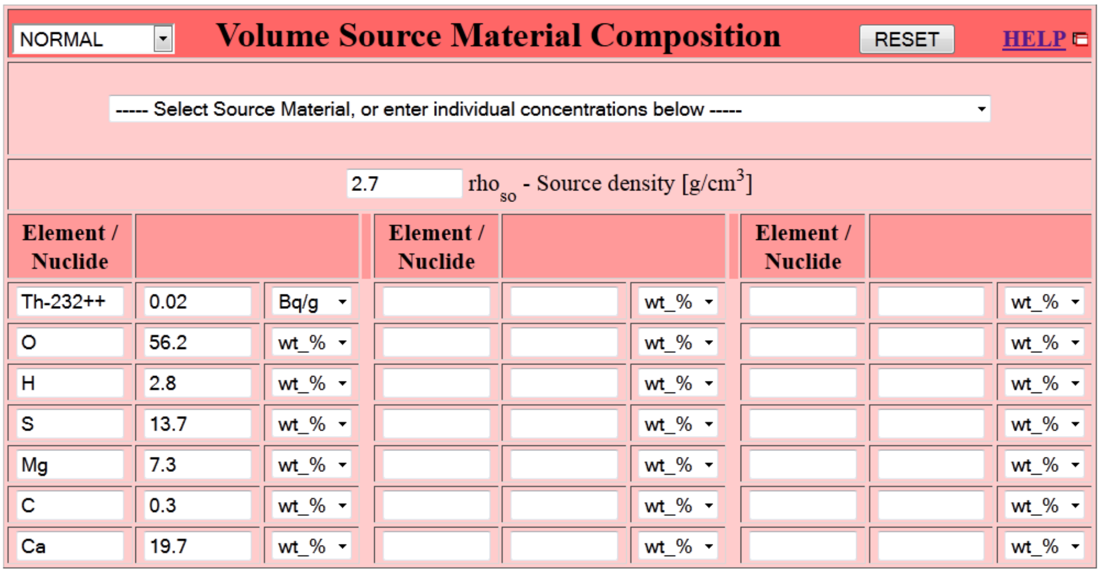


2.7 rho$_{so}$ - Source density [g/cm^3]

Element / Nuclide			Element / Nuclide			Element / Nuclide		
Th-232++	0.059	Bq/g	Mg	0.0	wt_%			wt_%
Fe	0.2	wt_%	Al	0.0	wt_%			wt_%
P	0.1	wt_%	Ce	0.0	wt_%			wt_%
O	54.8	wt_%	C	0.0	wt_%			wt_%
H	2.4	wt_%	Ca	22.7	wt_%			wt_%
Si	0.0	wt_%			wt_%			wt_%
S	18.4	wt_%			wt_%			wt_%

Abb. 6.3: Input parameters of the dose calculation for the WLP waste mixed 1:100 with gypsum

NUF waste stream

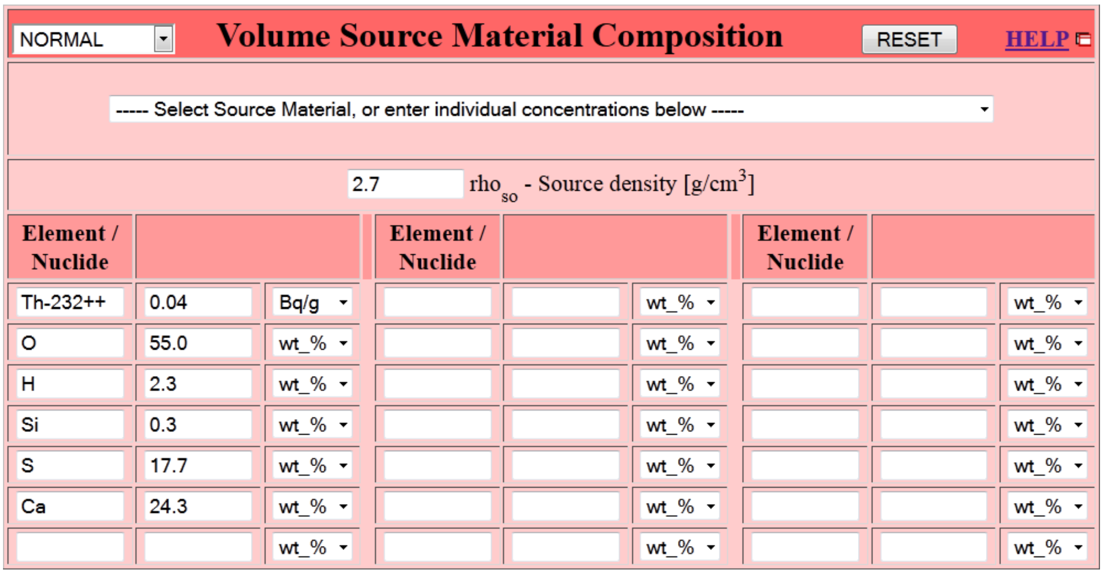


2.7 rho$_{so}$ - Source density [g/cm^3]

Element / Nuclide			Element / Nuclide			Element / Nuclide		
Th-232++	0.02	Bq/g			wt_%			wt_%
O	56.2	wt_%			wt_%			wt_%
H	2.8	wt_%			wt_%			wt_%
S	13.7	wt_%			wt_%			wt_%
Mg	7.3	wt_%			wt_%			wt_%
C	0.3	wt_%			wt_%			wt_%
Ca	19.7	wt_%			wt_%			wt_%

Fig. 6.4: Input parameters of the dose calculation for the NUF waste stream

FGD waste stream



Volume Source Material Composition

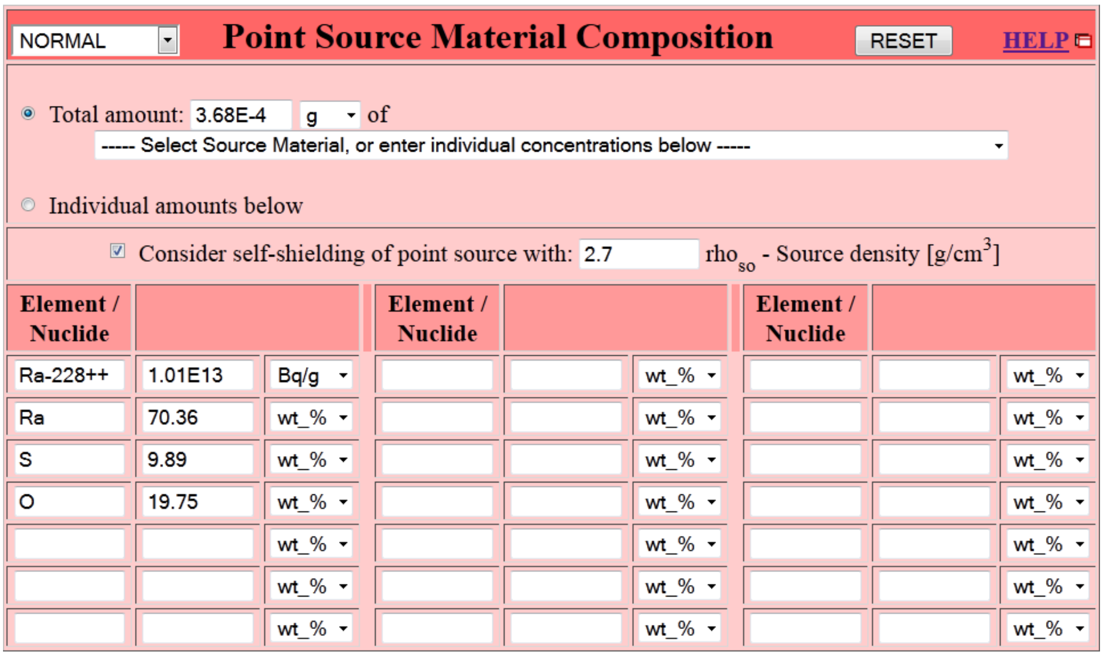
----- Select Source Material, or enter individual concentrations below -----

2.7 rho$_{so}$ - Source density [g/cm^3]

Element / Nuclide		
Th-232++	0.04	Bq/g
O	55.0	wt_%
H	2.3	wt_%
Si	0.3	wt_%
S	17.7	wt_%
Ca	24.3	wt_%
		wt_%

Fig. 6.5: Input parameters of the dose calculation for the FGD waste stream

Scale enrichment



Point Source Material Composition

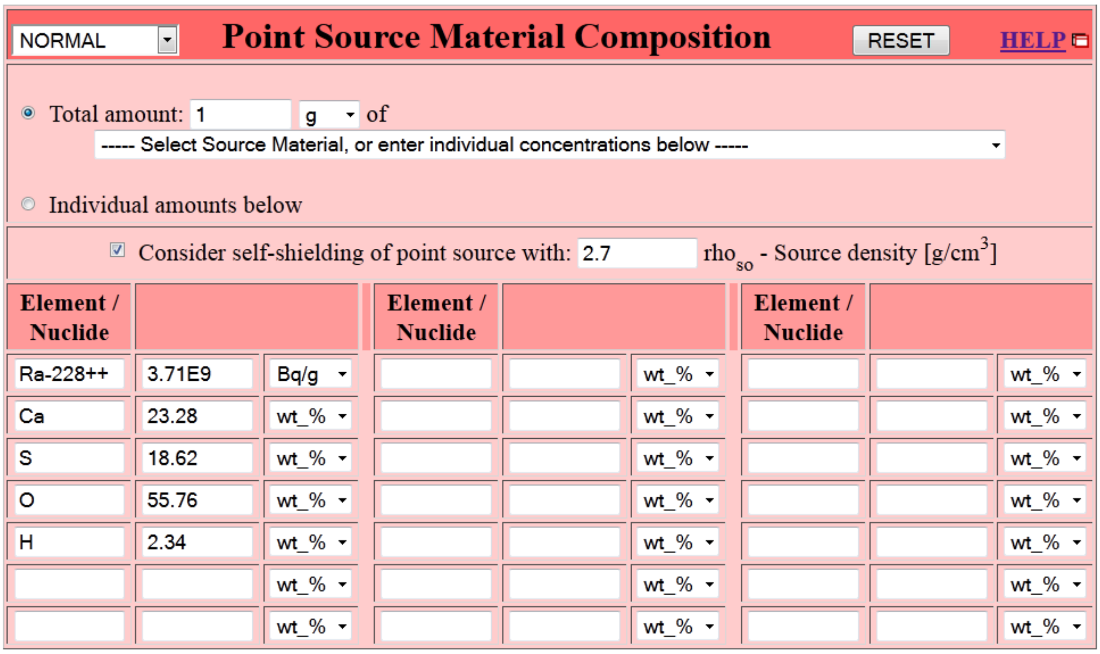
● Total amount: 3.68E-4 g of
----- Select Source Material, or enter individual concentrations below -----

○ Individual amounts below

☑ Consider self-shielding of point source with: 2.7 rho$_{so}$ - Source density [g/cm^3]

Element / Nuclide		
Ra-228++	1.01E13	Bq/g
Ra	70.36	wt_%
S	9.89	wt_%
O	19.75	wt_%
		wt_%
		wt_%
		wt_%

Fig. 6.6: Pure radium scale composition



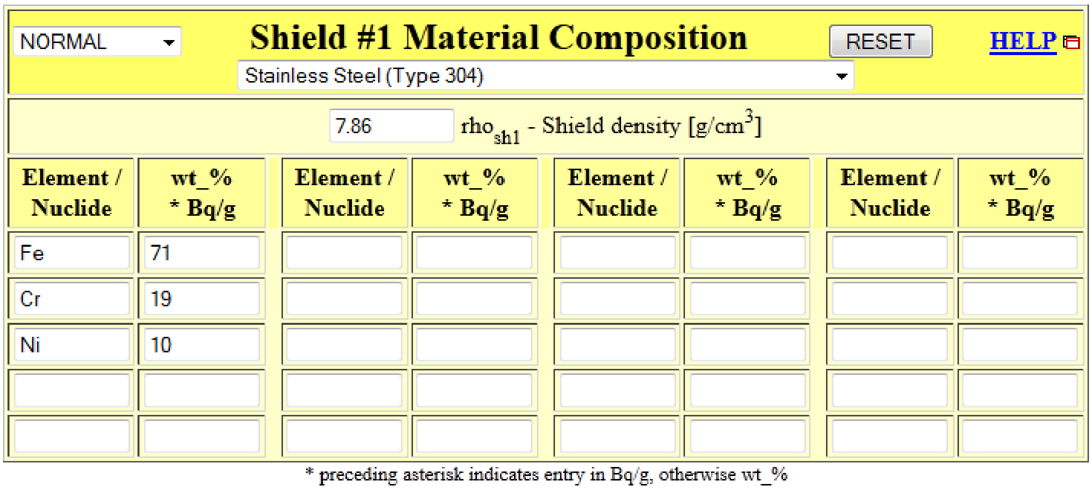
● Total amount: 1 g of
----- Select Source Material, or enter individual concentrations below -----

○ Individual amounts below

☑ Consider self-shielding of point source with: 2.7 ρ_{so} - Source density [g/cm^3]

Element / Nuclide			Element / Nuclide			Element / Nuclide		
Ra-228++	3.71E9	Bq/g			wt_%			wt_%
Ca	23.28	wt_%			wt_%			wt_%
S	18.62	wt_%			wt_%			wt_%
O	55.76	wt_%			wt_%			wt_%
H	2.34	wt_%			wt_%			wt_%
		wt_%			wt_%			wt_%
		wt_%			wt_%			wt_%

Fig. 6.7: Co-precipitation of radium scale with gypsum composition



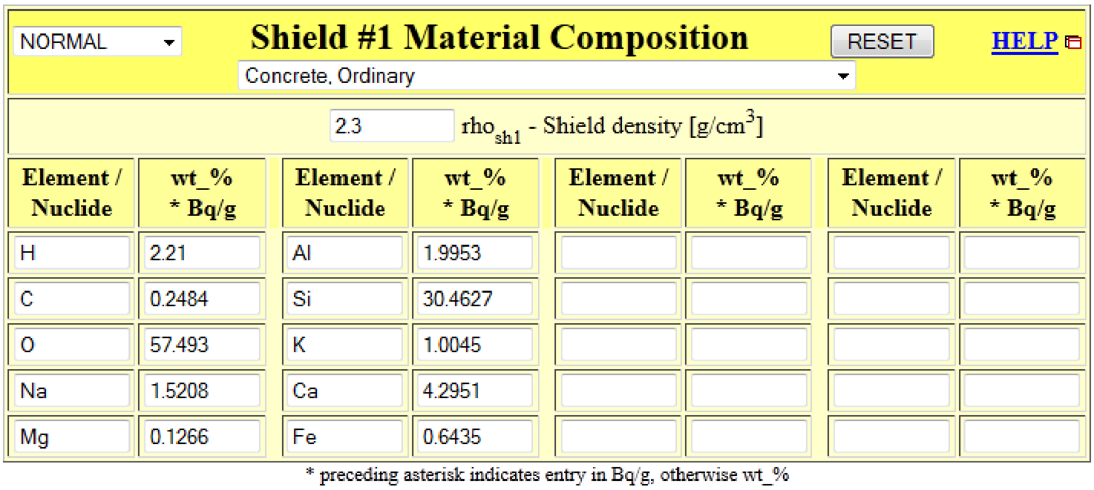
Stainless Steel (Type 304)

7.86 ρ_{sh1} - Shield density [g/cm^3]

Element / Nuclide	wt_% * Bq/g	Element / Nuclide	wt_% * Bq/g	Element / Nuclide	wt_% * Bq/g	Element / Nuclide	wt_% * Bq/g
Fe	71						
Cr	19						
Ni	10						

* preceding asterisk indicates entry in Bq/g, otherwise wt_%

Fig. 6.8: Composition of 5 mm steel shield layer



Shield #1 Material Composition

Concrete, Ordinary

2.3 ρ_{sh1} - Shield density [g/cm^3]

Element / Nuclide	wt_% * Bq/g	Element / Nuclide	wt_% * Bq/g	Element / Nuclide	wt_% * Bq/g	Element / Nuclide	wt_% * Bq/g
H	2.21	Al	1.9953				
C	0.2484	Si	30.4627				
O	57.493	K	1.0045				
Na	1.5208	Ca	4.2951				
Mg	0.1266	Fe	0.6435				

* preceding asterisk indicates entry in Bq/g, otherwise wt_%

Fig. 6.9: Composition of 10 cm concrete shielding