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A Life Cycle Assessment of a Uranium Mine in Namibia

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A Life Cycle Assessment of a Uranium Mine in Namibia

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Environmental Engineering
Department of Civil and Environmental Engineering
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DEDICATION

This thesis is dedicated to the people I met and learned from in Namibia: my friends and colleagues, other volunteers, and Peace Corps staff. The experience changed my life and I am glad to have this thesis as a reminder. I also dedicate this thesis to my family and friends that motivated and helped me through the process especially when all my motivation was lost.

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ABSTRACT

Uranium mining and nuclear power is a controversial topic as of late, especially in light of the recent Fukushima event. Although the actual use of nuclear fuel has minimal environmental impact, its issues come at the very beginning and end of the fuel's life cycle in both the mining and fuel disposal process. This paper focuses on a life cycle analysis (LCA) of uranium mine in the desert nation of Namibia in Southern Africa. The goal of this LCA is to evaluate the environmental effects of uranium mining. The LCA focuses on water and energy embodiment such that they can then be compared to other mines. The functional unit of the analysis is 1kg of yellowcake (uranium oxide). The processes considered include mining and milling at Langer Heinrich Uranium (LHU). The impact categories evaluated include the categories in ReCiPe assessment method with a focus of water depletion, and cumulative energy demand.

It was found that the major environmental impacts are marine ecotoxicity, human toxicity, freshwater eutrophication, and freshwater ecotoxicity. These mainly came from electricity consumption in the mining and milling process, especially electricity generated from hard coal. Milling tailings was also a contributor, especially for marine ecotoxicity and human toxicity. The other electricity generation types, including nuclear, hydro, natural gas, and diesel contribute to marine exotoxicity and human toxicity as well. Hydro-electricity, tailings form milling, sodium carbonate, and nuclear electricity also cause freshwater eutrophication at the LHU mine.

The major contributor of the water depletion was hard coal generated electricity consumption as well. Tailings also led to a level of water depletion that was significant but much smaller than that of the coal-based electricity.

In terms of energy, weighting portrayed the main energy used to be nuclear power, in terms of MJ equivalents. Nuclear power was then followed by fossil fuels and finally hydropower. Most of the energy used was for the uranium mining process rather than the milling process.

As expected, the direct water, and energy values, 0.5459 m^3 and 97.34 kWh per kg of yellowcake, were much lower than the LCA embodiment values of 282.67 m^3 and 76,479 kWh per kg of yellowcake. When compared to other mines, the water use at LHU was found to be much lower while the energy use was found to be much higher.

CHAPTER 1: INTRODUCTION

1.1 Introduction

This thesis is a life cycle study that focuses on assessing the embodied water and energy for mining and milling at a Namibian uranium mine called Langer Heinrich Uranium (LHU) that results in the production of yellowcake.

1.2 Rationale

Currently, there is limited literature on the embodied water and energy of Namibia's uranium mining process that includes the life stages of raw materials used and transport for example. The majority of the literature focuses on assessing pollution emissions associated with mining activities. Additionally, there are a small number of studies that focus on determining the embodied energy and water associated with the production of yellowcake. Most prior studies, shown in Table 1, focus on a Life Cycle Analysis (LCA) for the whole nuclear energy cycle rather than total energy and water usage specifically at a mine. Therefore, this paper will focus on energy and water embodiment for mining and milling at the LHU mine site.

Table 1.1 shows there are few prior studies that investigate environmental issues associated with Namibian mines, specifically the LHU mine. The LHU mine may become one of the more important mines as time passes with the low selling price of uranium because it has the highest percent uranium in its ore of all the currently operating Namibian uranium mines. [World Nuclear Association (WNA), 2016] Therefore, it is likely to be economically feasible to operate the mine even when that is not the case for other mines in Namibia like Trekkopje, one of the newer uranium mines in Namibia.

The extent of embodied water and energy in the Namibian mining sector is an important issue to study because the country has a very limited water supply [Beukes, 2011]; however, the country requires water for the majority of its economic livelihood that is associated with agriculture, industrial, and tourism. In addition, the mining companies are also concerned about lack of water because of the volume of water that the uranium mining process requires. To address this issue of water scarcity in mining locations, some mines are even implementing desalination to utilize brackish water. This thesis will thus provide the mining companies and government important information on the amount of water used during various life stages of the mining process. Also, electricity is relatively expensive in Namibia because it is mainly imported from South Africa. Therefore it is also important for mining companies to reduce consumption during the uranium mining process and an LCA can help companies to identify the stages that consume the most energy.

1.3 Problem Statement

The overall goal of this research is to use LCA to evaluate the environmental effects of uranium mining at the LHU mine in Namibia. As nuclear power becomes more advanced as a provider of global energy demand, uranium mining increases in importance throughout the world. In Namibia, mining is a huge part of the economy and uranium mining is increasing in importance and prospects. Although many studies have been performed for the Rossing mine in Namibia, because it is the main mine, the author of this thesis was interested in the LHU mine because it is the second largest mine in Namibia and LHU plans to utilize water from a desalination plant due to limited water resources in the desert country of Namibia.

1.4 Research Objectives

The objective of this research is to use LCA to determine the embodied water and energy associated with Namibia's uranium mining process at LHU. The end product from the uranium mining process is uranium oxide. This study focuses on the embodied energy and water consumption to produce one kilogram of uranium oxide (yellowcake).

Table 1.1 Previous Uranium Mine Studies Investigating Environmental Issues

Source	Location	Study Type
Lenzen, 2008	Australian U mines	LCA of energy balanace and GHG emissions
Dones, 2003	French and Swiss BWRs	Greenhouse gas emissions and LCA from electricity sources
Fritsche, 2006	German electricity systems	LCA of nuclear power and renewables
Doka, 2009	global/general U mines	General life cycle inventory
Kunakemakorn, 2011	McArthur River Mine (Canada)	LCA of nuclear power of European power reactor
Louw, 2012	Namibian U mines	LCA
Wiewiorra, 2010	Swedenf	LCAs on electricity sources
Cunningham, 2006	Trekkopje, Namibia	Environmental Impact Assessment
Mannheimer, 2006	Trekkopje, Namibia	Environmental Impact Assessment focused on vegetation
Pryor, 2009	Trekkopje, Namibia	Environmental Impact Assessment of desalination plant
National Renewable Energy Lab, 2013	USA	LCA comparison for nuclear and other electricity sources
Meier, 2002	USA	LCA comparison for nuclear and other electricity sources
Dones, 2005	Western European reactors	Ecoinvent Life cycle inventory for nuclear and natural gas systems
WNA, 2011	World (lit review)	LCA comparison for nuclear and other electricity sources
Lenzen, 2008	World (lit review)	Life cycle energy and greenhouse gases of nuclear power

1.5 Hypothesis

This study has one hypothesis: the LHU mine has high embodied energy and water for its uranium output due to its arid location and purchasing out of country electricity compared to other global uranium mining sites where evaluation results are available in literature.

CHAPTER 2: LITERATURE REVIEW

2.1 Nuclear Power and Uranium Mining in Namibia

2.1.1 Nuclear Power in Africa

Nuclear Power in Africa exists only in South Africa commercially, although some other countries such as Egypt, Libya, and Morocco have research reactors and related facilities. Uranium is mined in several locations in Africa including Namibia, Niger, Malawi, and South Africa. Uranium mined in Namibia is used throughout the world. In 2012, uranium mined in Namibia from the three main companies (Areva, Rossing and Langer Heinrich) alone were exported to France, Japan, the USA, Canada, the UK, Australia, Taiwan, Switzerland and Germany as well as to unspecified countries in Asia, Europe, and Africa [WNA, 2016].

2.1.2 Nuclear Fuel Cycle

Uranium mining, milling, conversion, enrichment, fabrication of fuel assemblies and waste handling are the major steps of the front-end of the nuclear fuel cycle. Transport and interim storage of fuel and spent fuel are additional steps towards the actual use of the fuel in the reactor. Reprocessing, plutonium and uranium recycling and final disposal of nuclear waste form the back-end of the nuclear fuel cycle [Martin, 2012]. To better differentiate various activity levels of the waste it is categorized as low active (LAW), medium active (MAW), and high active (HAW) [Kreusch, 2006]. Figure 2.1 shows a simplified version of a nuclear fuel cycle. Each step of the fuel cycle has different pollution and hazardous materials associated with it: for example, dust in the mines, radioactive materials in the facilities, contamination of groundwater and the environment due to final repositories. [Kreusch, 2006].

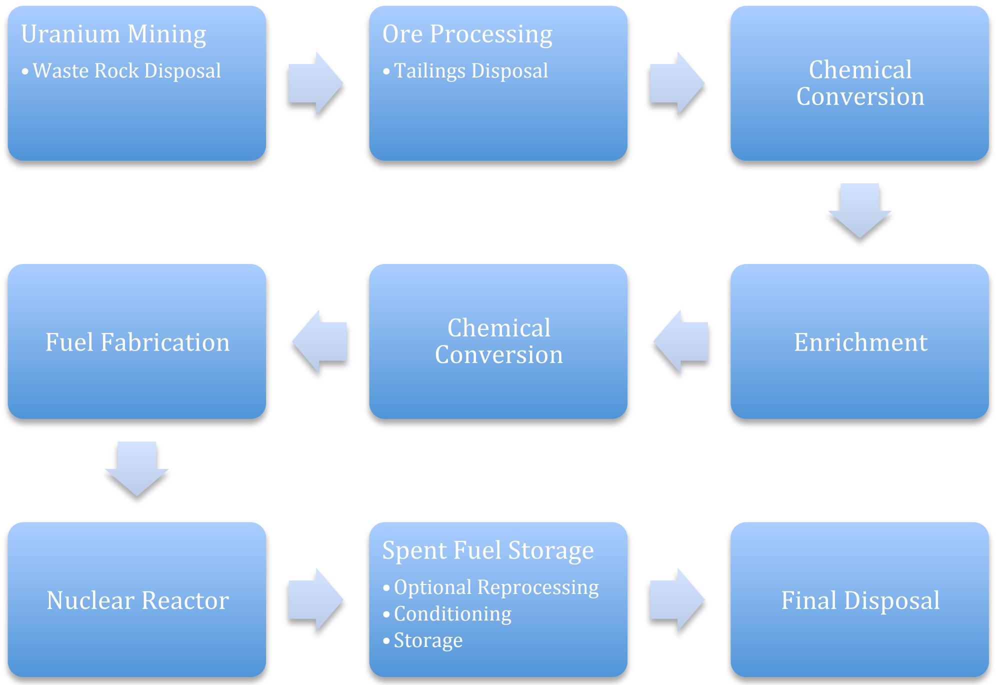

Figure 2.1 Simplified Nuclear Fuel Cycle.

2.1.3 Uranium Mining Worldwide

Uranium is used for most nuclear reactors. It is distributed in the earth's crust and oceans but can only be economically recovered when the concentration is sufficiently high. In the past, the majority of economically feasible uranium-bearing ores contained less than 0.5% of uranium. Mining still remains lucrative because one kilogram of uranium has as much energy potential as three million kilograms of coal [Martin, 2012]. However, extensive amounts of uranium are used due to many reactors and high outputs. For example, in 2011, it is estimated that 68,971 tons of uranium were used to power the 440 operating reactors [Martin, 2012].

Uranium ore is mined either by conventional open-pit or underground mining methods [Martin, 2012]. Deposits in groundwater and porous material can be mined via in situ leaching [Nilsson, 2008]. Usually, milling uranium involves crushing and grinding the ore [Puigmal, 2011]. Uranium is extracted from the crushed ore in a processing plant (mill) using chemical methods appropriate to the specific mineral form. These usually extract approximately 85% to 95% of the uranium present in the ore. The radioactivity of the separated uranium is very low. The radioactive daughter products are left with the mill tailings, stabilized, and placed back into the mine or otherwise disposed of [Martin, 2012].

Slurry containing fine ore particles is the output from ore processing. This is mainly UO2 and UO3. This slurry is then blended with sulfuric acid or carbonate leaching [Nilsson, 2008]. Leaching causes the uranium compounds to be recoverable. The recovery depends on the oxidation state of the uranium. Sometimes an oxidizer such as manganese dioxide, sodium chlorate, hydrogen peroxide, or oxygen is needed before leaching can be viable [Youlton, 2011].

Finally, the slurry is dried at high temperatures forming uranium oxide, which can be shipped to a processing facility [Puigmal, 2011]. The uranium oxide (U3O8), or yellowcake, usually contains between 60% and 85% uranium by weight [Martin, 2012]. Another process, solution mining or in-situ leaching, is when chemical solutions are passed through the ore bodies to directly dissolve the uranium. Sometimes uranium can even be recovered as a by-product from the extraction of other metals such as copper and gold. It can also be recovered as a by-product of the process used to obtain phosphoric acid from phosphate rocks [Martin, 2012].

Oxidizing pyrite and sulfides releases metals, acid and sulfate. This is referred to as acid rock/mine drainage, which causes the acidification of water. Acidification of water also increases the solubility, bioavailability and mobility of metals [Ashton, 2001].

The next steps for creating fuel rods are conversion, fabrication and enrichment. The yellowcake is chemically dissolved and converted back into uranium oxide/dioxide for processing in the fuel fabrication plant. It can also be further processed into uranium hexafluoride (UF6) for enrichment [Martin, 2012]. It is enriched to increase the amount of uranium-235, which is fissile (can undergo fission), so it is more efficient in reactors.

In general, uranium mines require the lowest amount of energy consumption per US dollar of product in comparison to other major mineral mining operations. Uranium mines also have the lowest average greenhouse gas emissions but one of the highest average consumptions of water. In comparison to copper and gold mining, uranium mining also has the highest injury frequency rate. Overall, the uranium mining industry shows a relatively good performance in terms of environmental impacts in comparison to other mining industries. [Nilsson, 2008]

The recoverable yield from a given resource is determined as a function of ore grade. Recovery rate, or yield, is directly related to ore grade or percent. A commonly used one is the Storm van Leeuwen and Smith's regression, which shows how recovery rate increases with ore grade [Lenzen, 2008].

In addition, each mining type requires different energy amounts based on the type. On average, only 50-70% of the uranium in a deposit can be mined. Using a mining model of an average deposit extraction lifetime of 10± 2 years for all existing and planned uranium mines up to 2030, the global mining peak is expected to reach a maximum of 58 ± kilotons in the year 2015[Dittmar, 2011]. For reference, the predicted peak of fossil fuels is estimated to be somewhere between 2005 [Murray, 2012] and 2025 or 2028 [Leggett, 2012].

2.1.4 Mining in Namibia

Namibia's GDP was reported to be US$12.3 billion in 2011. Namibia's economy is heavily reliant on the extraction and processing of minerals for export [Ruparelia, 2012]. Specifically, Namibia focuses on diamond and uranium mines but also consists of smaller copper, zinc and lead mines. Namibia is the fourth largest exporter of non-fuel minerals in Africa and the world's fifth largest producer in uranium (Rossing and Langer Heinrich uranium in fact accounts for about 10% of the world's uranium) [Harases, 2007]. Considering the small population and limited infrastructure, this is a surprisingly large feat. The mining industry has been the largest GDP contributor since Namibia's independence in 1990 [Kohrs, 2012] and employs approximately 14,000 people [Beukes, 2011]. Mining accounts for 50% of Namibia's foreign exchange earnings and is the largest private sector of employment [Harases, 2007].

Although most of Namibia's uranium ore is relatively low grade, it is still economically feasible to mine due to the current need for uranium to power nuclear reactors. Namibia, along with South Africa, has some of the lowest grade uranium that is mined throughout the world. The USA, Australia, and Mongolia have higher-grade mines while Canada has the highest uranium ore grades of all [Mudd, 2007]. The Namibian mining industry receives extensive foreign direct investment, which is vital because these investments equate to increasing available capital as well economic growth, which can reduce poverty and raise the standard of living [Boocock, 2002]. Investors include Australia, Canada, South Africa, Namibia, China, France, the UK and Russia. The mines also currently export all their uranium, in its raw form, to Japan, North America, Europe, and Asia. Specific country data is classified and not available [Shindondola-Mote, 2008]. Overall, countries that invest in uranium mines are usually ones that have nuclear reactors for power throughout their country. The World Nuclear Association (WNA) estimates that Namibia's Uranium Resources are about 5-7% of the world's known total resources [Puigmal, 2011]. Figure 2.2 shows the location of uranium licenses in Namibia.

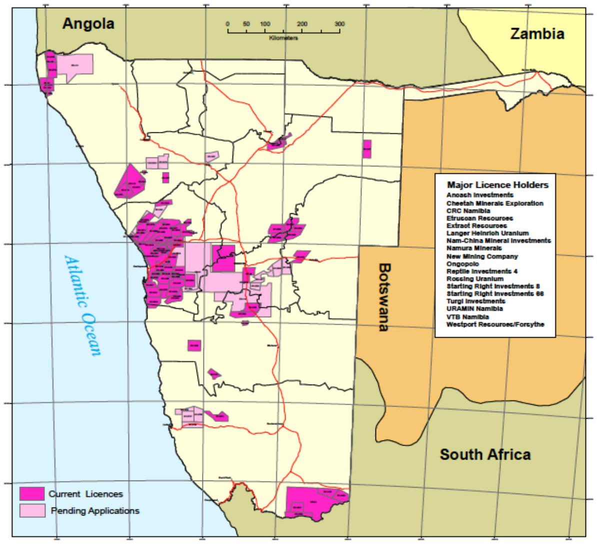

Figure 2.2 Current and Pending Uranium Licenses in Namibia.[1]

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[1] This figure was previously published in [Swiegers, 2008]. Permission is included in Appendix E

Namibia has an estimated reserve of 284,000 tons [Puigmal, 2011]. The recoverable resources are about 275,000 tons U with the "Reasonably Assured Resources" making up 176,000 tons, which are accessible by open pit mining [World Nuclear Association, 2013]. In 2007 and 2008, Namibia's output was 2879 and 4366 tons of uranium respectively [Swiegers, 2008]. Table 2.1 shows the uranium production in Namibia for the years 2008-2013.

Table 2.1 Namibia Uranium Production (Tons of Uranium). [adapted from World Nuclear Association, 2016]

Mine	LHU	Trekkopje	Rossing	Total
2008	919	0	3,449	4,368
2009	1,108	0	3,519	4,627
2010	1,419	0	3,083	4,502
2011	1,437	0	2,641	4,078
2012	1,960	251	2,289	4,500
2013	2,098	186	2,043	4,327

By 2015, Namibia's uranium output is expected to reach 25,961 tons. This value is estimated based upon 2009's output and the estimated new mines being built, resulting in an increase in the percent total GDP from 5% in 2009 to 15% in 2015 [Beukes, 2011]. From 2009 to 2015, the number of uranium mining employees is also expected to increase from 1,700 to 4,500 while the government profits are expected to increase from N$1.2 billion to N$2.6 billion [Beukes, 2011].

The current operating mines are Rossing, Langer Heinrich, and Trekkopje. The mines that are expected to start operating in the next two to five years include Etango, Husab, Omahol, and Valencia. The Aussinanis, Ripnes, and Marenica mines are currently in the exploration phase [Kohrs, 2012] (Figure 2.3). In addition, as of 2011, there are three operational mines but sixty-six recently granted prospecting licenses that could become mines [Puigmal, 2011].

Figure 2.3 Namibian Uranium Mine Sites.[2]

Table 2.2 shows the measured and assumed uranium reserves in Namibia. The Rossing Uranium Mine is a large open pit mine that started operating in 1976 and outputs approximately 4000 tones [Puigmal, 2011]. It started production in 1976 and contains four deposits: one large (50-100 kilotons) one medium (25-50 kilotons) and two smaller (5-10 kilotons). Production is planned to continue until 2016, possibly up to 2021. Even though it contains ore grades as low as 0.02%, it can still be mined efficiently [Dittmar, 2011]. It is 65 kilometers inland from Swakopmund [Kohrs, 2012]. The ore is mined in an open-pit then processed. The processing involves oxidation with ferric sulfate then dissolving in sulfuric acid. Then, the chemical processing, precipitation, filtration, drying and roasting produces uranium oxide or "yellow cake" [Lindemann, 2008]. The Rossing Uranium Mine is owned by Rio Tinto and is the world's largest open pit mine. It currently provides almost 8% of the world's demand for uranium. Rossing did not conduct an Environmental

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[2] This figure was previously published in [Kohrs, 2012]. Permission is included in Appendix E

Impact Assessment (EIA) before operations [Shindondola-Mote, 2008]. In December of 2005, Rossing was extended until 2016 and output also increased to 3400 tons of Uranium per year. In 2007, a further extension occurred and output increased again to 3800 tons Uranium/year from 2012 onward. Additionally, a sulfur burning acid plant was commissioned in 2008 such that 1200 tons are burned to create 9.5 MW net electricity. [World Nuclear Association, 2013] ISO 14001 environmental certification was received in 2001 and renewed in 2005 [Nilsson, 2008].

Table 2.2 Uranium Deposit Types and Amounts for Current Mines. [adapted from World Nuclear Association, 2016]

Namibian Mine	Resources Measured/Indicated (tons U)	Resources Assumed (tons U)
Rossing SJ	25,866 at 0.02%	2.035 at 0.017%
Rossing Z20	20,656 at 0.024%	25,354 at 0.022%
Langer Heinrich	57,500 at 0.055%	9,200 at 0.06%
Trekkopje	26,000 at <0.011%	3,000 at 0.01%
Husab	137,700 at 0.039%	50,000 at 0.029%
Norasa	39,700 at 0.0167%	8,500 at 0.014%
Etango	57,330 at 0.019%	24,630 at 0.016%
Marenica	2,500 at 0.010%	19,600 at 0.008%
Omahola	10,400 at 0.036%	6,950 at 0.036%
Tubas-TRS	0	10,900 at 0.0125%

The Husab mining project is owned by Taurus Minerals, which is part of China's CGNPC-Nuclear Fuel Co. Its construction started in February 2013 and the plan is to obtain up to 5770 tons of uranium per year for 2015-2017. In addition, Husab hopes to extend to include the Rossing South ore body. The Ministry of Mines and Energy (MME) approved a license for it in November 2011 and the Ministry of Environment and Tourism (MET) gave environmental approval in 2011 [World Nuclear Association, 2013].

Valencia Uranium P/L is a subsidiary of Forsys Metals Corp from Toronto, Ontario, Canada. It was granted environmental approval in June 2008 then obtained a mining license in August 2008.

The Valencia mining project is 25 km northeast of Rossing. It is indicated to have about 23,320 tons of uranium [World Nuclear Association, 2013]. Valencia is an open pit mine with an approximate cost of $188 million for its development [Southern Africa Resource Watch, 2008]. Forsys, via Dunefield Mining P/L, is also developing in the Namibpaas area with multiple deposits. The objective will be to produce 1900 tons of uranium per year starting in 2015 [World Nuclear Association, 2013].

Bannerman Resources is developing Etango, formerly called Goanikontes. Environmental approval was finalized in mid 2011 but a mining license is still progressing. Production is envisaged at 2700 tons Uranium/year [World Nuclear Association, 2013].

Zhonghe Resources (Namibia) Development P/L is a subsidiary of China National Nuclear Corporation (CNNC) plans to open pit mining and heap leaching for approximately 600 tons Uranium/year. The MME issued a mining license in November 2012 and the 2011 Environmental Impact Summary (EIS) was released in April 2013 [World Nuclear Association, 2013].

Areva is a global nuclear industry leader covering every part of the fuel cycle. It is the world's largest producer of uranium [Beukes, 2011]. Trekkopje is a large, shallow mine, owned by Areva [Shivolo, 2009]. It is expected to employ 950 workers, of which 98.5% will be Namibian [Beukes, 2011]. It plans to utilize a carbonate/bicarbonate heap leach process [World Nuclear Association, 2013]. Once commissioned, it is expected to process 100,000 tons of crushed ore per day creating about 3,000 tons of the product triuranium octoxide (U3O8). At the Trekkopje mine, the spent ore is planned to be used to fill the area behind the mine faces such that land loss is minimized. Yellowcake will be made from the triuranium octoxide via the Nimsix IEX technology along with two-stage precipitation. The facility containing the alkali heap leach pad will be 810 km wide and 3 km in length, making it one of the largest of its type in the world. Full production is expected to last twelve years, starting in 2012 [Beukes, 2011]. Production in 2012 was 251 tons of uranium [World Nuclear Association, 2013]. Water will be provided for the Trekkopje mine by the

Erongo desalination plant. This process involves filtration of seawater then reverse osmosis. The reverse osmosis process separates seawater into pure water and brine. The brine is returned to the ocean and the pure water is piped to the mine [Beukes, 2011].

The Langer Heinrich Uranium (LHU) mine is in the Namib Naukluft National Park and was completed at the end of 2006. It began operation in 2007 and was in full production by 2008 with an average output of 1,000 tones [Puigmal, 2011]. It is owned by Paladin Resources Ltd (now Paladin Energy) and consists of a deposit that is close to the surface and therefore comparatively easy to mine [Shindondola-Mote, 2008]. It is a surficial, calcrete type deposit that is extracted via alkaline leach and ion exchange process [Paladin Energy, 2012]. In 2010, 1.4 kilotons were produced and the target for 2 kilotons per year [Dittmar, 2011]. It has been upgraded twice. In the first, which was started in 2008 and finished by 2009, the expansion increased production by 40% [Beukes, 2011]. The development for Stage 3 increased production to 2000 tons Uranium/year, up from 1430 tons Uranium/year in 2009 after Stage 2. Production in 2012 was 1,960 tons of Uranium and the first half of 2013 was 996 tons. Stage 4 is proposed by mid 2014 [World Nuclear Association, 2013].

LHU employs 280 people along with 300 additional contractors who have permanent functions at the mine. Ninety-six percent of the workforce is Namibian or permanent residents [Beukes, 2011]. The EIA does not properly address loss of biodiversity (due to its place in the Namib Naukluft National Park) nor the possible ground and surface water contamination. There have been concerns that the EIA underestimates the radiation doses by approximately four times so their proposed tailing management plan is possibly seriously flawed [Shindondola-Mote, 2008]. Some proposed areas for LHU contain exclusive as well as endangered species. There are also incredibly old trees, mainly camel thorn that should be considered [Irish, 2009].

LHU will be the mine focused on in this research because of the availability of information and its general mining structure. The complete mining process for the LHU mine includes: open pit mining, crushing and grinding, extraction via alkaline leach and ion exchange processes, solids separation, tailings disposal, uranium extraction and barren liquids recycling, precipitating uranium, separating solids and recycling barren liquids, and drying.

2.2 Societal Impact

2.2.1 Sociological Impact

All resources should be thought of in terms of their overall impact including environmental and sociological effects, not just their costs and expenses. This is vitally important when health and the environment are at risk, as is often the case in communities effected by mining processes. However, the impact of this complex relationship is difficult to discern, as there are often both positive and negative effects. As previously mentioned, mining enhances the local economy and provides jobs. With these economic impacts come advances in infrastructure, healthcare, and other social factors. The correlation between enhanced economic status and better health care is clear [Boocock, 2002]. This can also be linked to increased employment in sectors even outside of mining and improved infrastructure from enhanced roadways to better schools [Boocock, 2002]. Anecdotal evidence suggests that many mines in Namibia, especially Rossing, have programs for workers and their families. These include education, health, business and other programs to increase quality of life. Mines also make roads and facilities better for the community if they are necessary for productive mining activity.

Unfortunately, these same areas are affected by land acquisition, the effects of changes in land usage, the rapid growth of the mine, and environmental impacts. Thus, in areas of high poverty , the near-by communities may respond in an unpredictable and volatile ways. Examples exist of communities either embracing the mine or reacting in protest, strike, and even violence. Losing community land is an especially volatile issue when traditional leaders had been given the land and companies or the government takes it. Losing this land may results in the loss of livelihood for those involved in land use activities such as herding or farming. When this occurs, more and more people because dependent on the mine for jobs, potentially resulting in issues with sustainability due to local dependence on mining and its related infrastructure [Veiga, 2001]. Appendix A expands on these issues of security including the uranium specific impacts on nuclear safeguards and nonproliferation.

It is also important to note the effects of mining on local traditions and culture, increased risks of sexually transmitted diseases (STDs), the increase of basic commodity prices, population displacements, land use conflicts, and loss of some livelihoods especially those related to livestock, tourism and farming [Boocock, 2002]. Uranium mining usually causes individuals and their families to migrate to the mines from other areas of the country. Such migration has been known to place stress on the local infrastructure, as resource poor areas are often ill equipped to handle a massive influx of migrant [Kohrs, 2012]. Abundant research also suggests that rates of HIV/AIDS increase with the opening of mines and along the associated transportation routes [Kohrs, 2012]. There is also data to suggest that, when mining is complete, the surrounding community becomes a 'ghost town' or often falls back into poverty [Kohrs, 2012].

2.2.2 Health Impacts

The act of mining creates many occupational and environmental hazards including exposure to pollution from mining and ore processing as well as pulmonary diseases due to dust inhalation (silicosis). Mining can also lead to respiratory diseases and cancer linked to gas flaring [Calain, 2012]. Mining and ore processing can cause mercury and lead pollution, which are two of the worst toxic pollutions. The Blacksmith Institute, an international environmental nongovernmental organization (NGO), lists mercury and lead pollution from mining and ore processing in their list of the top ten worst toxic pollution problems worldwide [Calain, 2012].

General effects of mining industries are likely to occur through impacts on arable land and water resources. For instance, in the Democratic Republic of the Congo (DRC), chronic childhood malnutrition is higher in regions that rely on the mining industry. The stunting in these regions is higher than elsewhere in the country, even in the regions that are at war [Calain, 2012]. Changing the landscape can also lead to health issues such as malaria epidemics in arid areas when the digging of the mines creates standing water [Jasparro, 2009].

Residents near uranium mines are exposed to toxins in mining waste. These include radiation from the majority of mining activities including milling and other processing. A small increase in chromosome aberrations is occasionally found. In one study, cells from the target population had a significantly abnormal DNA repair response when compared to those in the general population. Due to this study, it appears that the main health issues for those living near mines comes from the radiation, just like the workers of the mines [Stephens, 2001]. Radioactive particles can be blown in the wind as well as seeping into the soil and groundwater [Wiewiorra, 2010].

2.2.3 Worker Safety

As the industry has become more modern, the working conditions have improved. Nonetheless, conditions are still reported as poor according to employees. Uranium mining creates health risks for the people working in the mines as well as those living nearby. Although uranium companies in general do not acknowledge radiation related occupational health disease, workers have been suffering from cancer and other diseases that they link to their work in the mines [Kohrs, 2012]. Long-term occupational health hazards are especially important in uranium mining [Stephens, 2001].

Most uranium mining studies focus on lung cancer; lung cancer is a type of ionizing radiation-induced occupational cancer. The main cause of lung cancer is alpha emitters, which are inhaled into the lungs such as thorium-232 and radium-226 [Wiewiorra, 2010]. Uranium mining produces both dusts and gases. Radon-222, created from the decay of Uranium-238, is extremely unsafe for inhalation [Stephens, 2001]. There have been studies in Namibia on uranium mineworker health. It has been determined that the lifetime risk of cancer is between 1 in 25 to 1 in

9. There was also a study in which changes were discovered in the chromosomes of workers' white blood cells. The government then banned further work and Rossing hired experts to refute it [Kohrs, 2012]. It seems that workers are not informed of the dangers they face due to dust and gases at the mines. Respiratory problems are common and workers do not trust Rossing's medical staff.

Recent research has begun to focus on the biological impacts of mining. For example, one study in Namibia focused on the effect of uranium mining on workers' genes. Results included a six-fold increase in uranium excretion, a reduction in testosterone levels and lower neutrophil counts. The low levels of neutrophil counts are probably due to chronic radiation injury of the hematopoietic system. Low hormone levels also imply a damaged gonadal endocrine system. In addition, a threefold increase in chromosome aberrations was noted. Finally, cells with multiple aberrations such as "rogue" cells were observed for the first time in miners. These types of cells had only been previously seen due to massive, quick exposure at disasters such as Hiroshima and Chernobyl [Stephens, 2001].

2.2.4 Ecosystem Impacts

Many of the uranium deposits are in the Namib Naukluft Park, which is a protected area. There are also some deposits in the newly appointed Dorob Park. Both of these parks are destinations for tourism and ecological conservation and they are not legally meant to be used for heavy industrial development [Kohrs, 2012]. For more information on legislation related to uranium mining in Namibia, see Appendix B.

The Central Namib Desert is characterized as one of the oldest and most diverse deserts in the world as it contains over 400 species of plants and about 10% of Namibia's flora. Additionally, more than 30% of plant species are believed to exist only in the Central Namib Desert. This is so pronounced that EIAs in the area often discover new or rare species in the area. Since the majority of the plants are very slow growing, a short change due to mining would nonetheless create a massive change in the local flora. The Waterberg sand lizard is of high concern as well as the lichen fields east of Wlozkasbaken [Kohrs, 2012].

2.3 Environmental Concerns

2.3.1 Pollution Caused from Uranium Mining

Southern African countries have 'Environmental Sustainability Index' scores near environmental vulnerability. Southern Africa is also a region identified by the German Advisory Council on Global Change expected to be severely effected by global climate change [Jasparro, 2009]. Issues such as desertification, water scarcity, and deforestation will continue to get worse. Population Action International (PAI)'s analysis named Namibia as having an elevated risk [Jasparro, 2009]. This means that as population increases, environmental factors are likely to produce instability and perhaps even conflicts.

The mining of uranium creates residue of heavy metal of radioactive decayed elements. The residues are usually put in ponds or dams nearby and can leach into other water sources as well as the ground. They can even spill out and cause major catastrophes [Puigmal, 2011]. Stricter environmental and worker regulations in developed countries like the United States and Australia makes it less expensive to mine in poorer countries, which usually have limited mining regulations [Puigmal, 2011]. Namibia, being a relatively young country (it gained its independence in 1990) is a perfect example of this. Although it has a few legislative Acts, their implementation is weak. There is only one person in charge of the Environmental Impact Analyses for the whole country and only five entrusted with monitoring water quality. There is also the Chamber of Mines but it is "not legally binding and is not independently monitored" [Puigmal, 2011].

The Directorate of Environmental Affairs of Namibia's Ministry of Environment and Tourism works to provide relevant environmental information to policy, planning and decision-making processes through the State of Environmental Reporting System [Rena, 2012]. In addition, when a mine is closed, the mining company must arrange for tailings and waste rock dumps although there is currently no legislation requiring them to do so [Kohrs, 2012].

An International Atomic Energy Agency (IAEA) publication focuses on an environmental impact study of radiation releases and rehabilitation in the Uranium Mines of Australia [Mudd, 2002]. It states the importance of regulating Rn-222 and its decay products, which create ionizing radiation doses in workers and are released during mining. The concentration of Rn-222 and its decay products varies immensely based upon soil type as well as tailings management. In Australia, they have varied from <0.37 to 4,440 GBq/day [Mudd, 2002]. The article also mentions gamma radiation due to residual gamma sources. These indicate potential uranium mineralization. Some gamma sources cannot be found until they are uncovered because they are underneath sedimentary or other geological formations. This causes undetectable gamma counts due to gamma rays' limited ability to pass through most substances.

The uranium mining in Mali has left groundwater contaminated with radioactive waste; as a result, health issues such as cancer, stillbirths and genetic defects are emerging [Abdalla, 2009]. The World Health Organization (WHO) recommended a maximum of 30 μg/l for uranium in drinking water in 2003, later lowering the maximum concentration to 15 μg/l in 2005. However, additional studies have concluded that 2 μg/l should be the maximum limit to prevent health concerns. Uranium in drinking water can lead to kidney and liver failure as well as blindness, paralysis and loss of coordination. It may also cause mutations, aberrant sperm, connective tissue and blood diseases, and changes in immune and endocrine systems, tumors and cancer. These effects are due to both uranium and its decay products: Uranium-238, Thorium-234, Protactinium-234, Uranium-234, Thorium-230, Radium-226, Radon-222, Polonium-218, Lead-214, Bisthmuth-214, Polonium-214, Lead-210, Bismuth-210 and Polonium-210 [Van Eeden, 2009].

Throughout the mining stages, various impacts are possible. For instance the exploration and surveying stage causes vegetation damage and removal, soil erosion, noise and vibration disturbances, water and electricity usage, discharge and dumping of wastes. Mine startup causes the same impacts as exploration as well as altering landforms and drainage flows, contaminating surface and groundwaters, air pollutants and destruction of additional areas. The removal and storage of ores and waste causes even more air and water pollution along with land alienation. The blasting, milling and grinding phase causes additional contaminants to the ground and air especially from explosives, transport, discharges, including sulfur dioxide emissions from acid plants. Smelting and refining also releases toxics in the air such as heavy metals, corrosive liquids, organics, and sulfur dioxide. When the mine is closed, there is slumping and flooding of previous mining areas along with acid rock drainage. There is a usually continuous discharge due to seepage too. Some areas may even need to be closed off since there are hazards such as pits and shafts [Ashton, 2001].

2.3.2 Wastes Produced

2.3.2.1 Tailings

There is also the need of an analysis of the uranium production facility life cycle because it can be seen that "major impacts can arise at all stages of the life cycle" [Falck, 2011]. This mining has the potential to contaminate via ionizing radiation, radon gas and other radionuclides [Pretorius, 2010]. Stored tailings are kept in artificial pools, ponds or dams. Tailings are the major contributor to the environmental damage and pollution caused by nuclear energy [Doka, 2008]. Mine tailings amount to 18 billion cubic meters annually throughout the mining industry. This is expected to double in the next 20 or 30 years as lower grade ore is starting to be utilized. Surface mining generates the most waste, accounting for 99% of waste but only 80% of minerals globally [Nilsson, 2008]. SimaPro uses the Ecoinvent database that assumes an 80000-year timeframe for emissions from uranium mining and milling sites. "These processes release pollutants to 'air, low population density', to 'water, river' and to 'water, ground' over very long time scales" [Frischknecht, 2005].

There is, on average, 500kg of tailings created per kilogram of useful uranium oxide [Doka, 2008]. These tailings contain various pollutants including arsenic, selenium, mercury, cadmium, molybdenum, lead, and copper. Including all aspects of the fuel chain, 72% of the emissions are from tailings including non-radiological air emissions, non-radiological water emissions, and Radon-22 emissions [Doka, 2008]. A disposal model could be used for uranium tailings emissions in a long-term scenario [Doka, 2008]. In dry sites, a major concern is pollution in the air and soil. If the water table is penetrated, even greater concerns include water pollution, which would spread quickly.

2.3.2.2 Ground Pollution

Mining is by nature environmentally invasive, expensive and socially intrusive [Beukes, 2011]. Waste rock from uranium mining and milling wastes include radium and other naturally occurring radioactive substances. These wastes are optimally disposed of in engineered geological facilities, which are covered on top and sealed underneath and on the sides in order to reduce radon emissions and the movement of groundwater. Wastes from the conversion process may contain uranium, acids and some organic chemicals [Martin, 2012]. Namibia has two hazardous landfills: one at Kupferberg near Windhoek and one at Walvis Bay. Low active waste (LAW), including depleted tailings, ore, and leach residues, are disposed of on licensed sites at mines [Louw, 2012].

The residue from the milling process, uranium mill tailings, is in the form of slurry. The largest uranium mill tailings dam is likely to be the Rossing uranium mine in Namibia as it contains more than 350 million t of the radioactive slurry. This slurry contains a portion of the uranium removed in the mining process as well as long life decay products produced by uranium including thorium-230 and radium-226. This means that the slurry contains about 85% of the initial ore radioactivity. It also contains chemicals used in the mining and milling process including heavy metals, chemical regents and contaminants such as arsenic. Radionuclides in the tailings typically discharge 20-100 times as much gamma radiation as the background [Kreusch, 2006]. Tailings also contain toxic materials like arsenopyrite and can increase acid generation in surrounding rock. The oxidation of pyrite creates an acid that is very damaging to the environment [Youlton, 2011]. The oxidation of the sulfide mineral into dissolved iron, sulfate and hydrogen. The sulfuric acid can then cause a decrease in pH along with more total dissolved solids (TDS). Ferrous iron (Fe (II)) can also be oxidized to ferric ion (Fe (III)). Sulfur and sulfide (-II) is then oxidized to sulfate if there is a low pH (2.3-3.5). This also converts the iron reduced back to its ferrous form [Nilsson, 2008].

The uranium ore processing steps also include sulfuric acid as a leaching agent. It can be neutralized so may not be a concern [Nilsson, 2008]. The effects of acid mine drainage include health threats to aquatic species, habitat and plant life, groundwater and drinking water pollution, decline in soil quality, and release of heavy metals that are usually contained by soil [Nilsson, 2008]. Some conversion facilities recycle such wastes to uranium mines in order to recover the uranium content while others dispose of their waste directly. Wastes arising from the uranium enrichment and fuel fabrication processes contain essentially small amounts of uranium and the associated naturally occurring radioactive elements. Uranium is considered to have a low radio-toxicity, but the same is not true for plutonium. The treatment of wastes in order to separate the plutonium and uranium, and the subsequent waste conditioning, results in a typical value for the quantity of plutonium as 0.01% of the initial plutonium [Martin, 2012]. The dry, fine sands from a pile are blown by the wind over adjacent areas and elevated levels of radium can subsequently be found in dust samples in nearby communities. Seepage from tailings is another major hazard and poses a risk of contamination of both ground and surface water [Tandlich, 2012].

Occasionally, a process called heap leaching is used to recover uranium from ore that is of a low grade. An alkaline or acidic leaching liquid is used which pollutes the environment in addition to the low level radiation from the uranium. This leaching agent is very strong and leads to environmental degradation. In addition, a leaching agent is also used in some mines that utilize the solution mining or in situ leaching process. This process involves pumping the liquid to the drill holes such that it can absorb the uranium and the solution can be brought up to the surface. This process directly pollutes the ground including the water table [Kreusch, 2006]. The use of acid in situ leaching (ISL) was never approved for use on commercial scale in the United States. It has been researched but was always considered problematic [Mudd, 2000].

Sulfuric acid, soda ash, bicarbonate, phosphoric acid, and caustic soda are used for uranium mining and there are plans to build a plant for each in the near future. Gecko Chemicals, an African company, has chosen three sites just north of Swakopmund and the fourth at Walvis Bay, behind the well-known Dune 7 [Kohrs, 2012]. These are all near tourist environmental areas and are also quite close to the large tourist town of Swakopmund.

Seepage is an especially important concern due to its mobile properties. The seepage usually has a very high contaminant load including sulfate, arsenic and uranium. Extreme weather such as floods and earthquakes can exacerbate the issue of seepage and cause containment structures to fail thereby spreading the slurry throughout the area [Kreusch, 2006].

Air pollution is another major concern in uranium mining. Radon, a radioactive gas, exists in uranium mines due to the continuous decay of radioactive substances in uranium mill tailings. Radon escapes from the piles and spreads with the wind and increases the lifetime lung cancer risk of residents living near a tailing pile [Tandlich, 2012]. The EPA estimated that deposits of tailings in the United States in 1983 would cause approximately 500 lung cancer deaths per century, (assuming no countermeasures are taken) [Kreusch, 2006]. Additionally, uranium mining releases extensive carbon dioxide emissions. Rossing's mine was found to emit 45.3 tons of CO_2 per ton of U3O8 produced [Mudd, 2007]. Dust and contaminants from the mining explosives are also an issue. In addition, one ton of explosives produces 40-50 cubic meters of nitrogen oxides as well as lots of dust [Nilsson, 2008].

2.3.2.3 Water Pollution

During the operation of the mines, large volumes of contaminated water are released, usually pumped into rivers and lakes thereby spreading to the environment [Kreusch, 2006]. Radioactive contamination of surface and groundwater is also a concern [Kohrs, 2012]. Runoff from mining operations can cause incredible damage to the groundwater supply, quickly spreading pollutants and contaminating various boreholes as well as rivers and streams. This is an especially detrimental effect when the country has a limited supply of water, as Namibia does. Namibia lacks water especially in the southern, desert portion of the country where the uranium mines are. During the dry seasons, the entire country lacks sufficient water as well. In Namibia, the groundwater is used for urban water supply, irrigation (Grootfontein/Tsumeb, Stampriet aquifers), mining, and rural water supply [Bann, 2012]. The demand of water is so severe that Namibia has drafted a long-term strategic water supply plan, which includes a new dam in the south (Heckartal Dam for irrigation in the Karas region) as well as using the Okavango river in the northern and central regions along with Windhoek, the capital city. It also includes a plan for the desalination of seawater specifically for the uranium mining industry [Beukes, 2011].

The uranium mining process is similar to coal mining, with both open pit and underground mines. It produces similar environmental impacts, with the added hazard that uranium mine tailings are low-level radioactive. When pumps are shut down after the closure of mines the risk of water contamination increases, very similar to the AMD challenges from coal and gold mines, with the additional threat of radioactive pollution. Groundwater can be polluted not only from the heavy metals present in mine waste, but also from the traces of radioactive elements still left in the waste [Tandlich, 2012]. Heavy metals from AMD are mostly those connected to sulfide ores and include arsenic, cadmium, copper, lead and zinc. AMD in uranium mines creates oxides as pitchblende and secondary ores formed from pitchblende by weathering. AMD leads to a lowering of the pH in aquatic systems due to sulfides. A lower pH also leads to silicates being weathered, which decreases their buffering ability and consumption of hydrogen ions [Nilsson, 2008].

The mining impacts on ground and surface water are severe and continue long after mines are closed. They lead to negative impacts on human and wildlife habitats [Martin, 2012]. As land becomes more arid from climate change causing the existence of limited surface water resources, the dependence on groundwater for commercial and domestic needs increases. The increase of population and industrial developments, including mining, are causing polluted, unsafe groundwater sources. These changes, in addition to climate change and drought, are causing the degradation of groundwater-dependent ecosystems (GDEs) [Bann, 2012]. The volume of acid mine drainage can account for up to 10% of the potable water resources in a metropolitan area [Tandlich, 2012]. Since Namibia has very low rainfall, it will take a long time for pollutants to reach the groundwater table. Due to this, the groundwater must be consistently monitored [Kohrs, 2012]. The tailings from uranium consist of many products that must be sufficiently contained for hundreds of thousands of years to safely avoid environmental hazards. This is due to the extremely long half-life (and therefore slow decay rate) of many of the contaminants. These include thorium-230 and radium-226, which decays to radon-222, a carcinogenic gas [Kohrs, 2012]. In addition, the uranium decay chain includes Pb-210 and Po-210 [Nilsson, 2008].

Since Uranium-234 is more rapidly dissolved in water than Uranium-238, aquatic environments have more Uranium-234 which is also much more radioactive. Since radioactivity in the water is often measured using Uranium-238 only, the calculated value is underestimating the amount of Uranium actually present [Winde, 2010].

The Commission de Recherché et Information Indépendantes sur la Radioactivité (CRIIRAD) performed a study in September 2011 near the Rossing and Langer Heinrich mines. They collected samples of soil, sediment and water as well as taking radiological measurements throughout the Namib Desert. Preliminary findings include a high dose rate at the public parking lot of Rossing (0.9

micro-Sieverts per hour compared to a natural background rate of 0.15 micro-Sieverts per hour) and a lack of confinement and fencing for the waste rock dump. The topsoil up to 2 km away was also found to be contaminated by tailings due to high levels of radium-226 (960 - 7400 Bq/kg). Additionally, the groundwater downstream from Rossing contained high levels of uranium in both the Khan and Swakop Rivers [Kohrs, 2012].

Radioactive and other hazardous substances like arsenic may contaminate drinking water supplies and fish in the area [Martin, 2012]. Dam effluent and the tailing of mines also has high nitrates concentrations, trace amounts of platinum-group metals and heavy metals like vanadium. Radioactivity can occasionally contaminate water sources too [Tandlich, 2012]. Exposure to radionuclide mining and extraction is a specific hazard. For example, concerns are being voiced over the environmental contamination of soil and potable water along with inhaled dust and urban constructions around the uranium mines in northern Niger [Calain, 2012].

The contaminants from the mining process can have various effects. Dissolved metals can cause acidic saline conditions in water. Also nutrient enrichment occurs due to oxidation and blasting residues. Eutrophication will occur along with decreased oxygen content and pH fluctuations from sewage discharges [Ashton, 2001]. Radionuclide seepage is also a concern specific to uranium mining.

During mining and after closure, water management is essential to avoid environmental risks. Strategies include routing surface drainage away from hazards, preventing liquid infiltration on tailings, promptly removing pit water to reduce acid generation, and separating out contaminated water from uncontaminated to reduce the quantity to treat. In many cases, contaminated water must be treated for many years after the end of mining [Schwarz, 2009].

2.3.3 Bioremediation and Reclamation

Pollution from mining and related operations poses serious environmental problems. Bioremediation has been estimated at about N$3000 per million liters (about 400 USD per ML) for acid mine drainage [Tandlich, 2012]. Treatment is feasible but expensive. The government will have to assist companies in many cases. In addition to dealing with closing the mines, related infrastructure must also be dealt with. For instance, roads and buildings should be transformed to resemble the previous biophysical environment as much as possible [Veiga, 2001].

Table 2.3 shows the cost of land for various mining tasks. This table shows that the environmental management and permitting/approvals are the main expenditures. In addition, all Paladin mines, like LHU, have a closure plan that minimizes environmental and social impacts [Paladin Energy, 2012].

Table 2.3 Land Cost ($N) for LHU Mine Tasks. [adapted from Paladin Energy, 2012]

Task	Estimated Cost 2011/2012
Waste Disposal	29,000
Remediation	18,500
Prevention	228,000
Environmental Management	825,000
Licensing	53,000
Permitting/Approvals	610,000

Environmental rehabilitation costs must be accounted for in all mining projects. The assurance that funds will be available at the closure of the mine should be part of the mining plan presented to the government before the opening of the mine. Lack of rehabilitation provisions will cause the abandonment of a hazardous site or the usage of government funds to deal with the issue. Therefore, bank guarantees or dedicated trust funds should be in place to deal with closure and rehabilitation costs [Boocock, 2002]. Rehabilitation includes restoring the productivity of the affected land area, harmonizing the landscape and reducing the risks of further land degradation. Rehabilitation can also involve deposits of peat, which are frequently reported to act as a filter for U and other heavy metals. Since 99% of all known peat deposits are in humid regions of the northern hemisphere, peat in southern Africa is a very scarce resource [Winde, 2011] so it is not a real option. Depending on the mining method, climate, soil, and hydrology, the following components may be included in rehabilitation:

- Remove and retain topsoil that can be spread in the area of rehabilitation
- Reshape the degraded areas and waste dumps for them to be stable, well drained, and suitably landscaped
- Minimize the potentiality of wind and water erosion
- Vegetate the area to control erosion and facilitate the development of a stable ecosystem [Nilsson, 2008]

Substantial clean up and disposal must occur when closing a uranium mine. Groundwater must be restored and waste slurries safely disposed. Tailings are often dumped on the surface with hopes that the ground will act like a filter to diffuse and absorb most of the pollution before it reaches the water table [Kreusch, 2006]. Technology is also advancing so waste can be remediated or used in reprocessing plants.

Additionally, there is a new organization, The Namib Ecological Restoration and Monitoring Unit (NERMU), planning to focus “exclusively on the challenges and opportunities for biodiversity conservation and environmental stewardship that mining will bring” [The Namib Ecological Restoration and Monitoring Unit, 2003]. NERMU believes that mining development is understandable but measures must be taken to ensure minimal environmental damage along with the maximum benefit to humanity as a whole. They work to monitor over twenty indicators for the Environmental Quality Objectives (EQOs). They also work with both the public and government to ensure a mutual understanding of environmental concerns. Their research and monitoring will be helpful to mining companies such that they can gauge their impacts and provide better management options [The Namib Ecological Restoration and Monitoring Unit, 2003].

2.3.4 Namibian Uranium Mining Water and Electricity Use

Uranium mining utilizes extensive water and electricity. Although Namibia has good infrastructure, mines are isolated due to their large land needs and location within a desert. The surroundings also require water for herding and farming as well as use for the general population.

2.3.4.1 Climate

The temperature in the Namib Desert, where most mining operations are located, varies from 27-30 degrees Celsius during the summer to 8-12 degrees Celsius in the winter. The temperatures are higher at sites further from the coast. Precipitation is about 15mm at the coast and 35mm inland. It is extremely variable and unreliable but some fog and dew exists. Winds are also strong, especially close to the coast [Pretorius, 2010]. At the coast they are approximately 3 meters/second. Namibia is classified as a hyper-arid country so water is a major concern. Ninety-eight percent of the land is deemed to be arid or semi arid. In addition, the demand of water is also increasing due to urbanization as well as population and industry growth [Pryor, 2009]. Figure 2.4 shows how rare water is in Namibia since the majority of the country is desert. It can be seen that Namibia only has rivers and green regions in the northeast area, which is far from the mines.

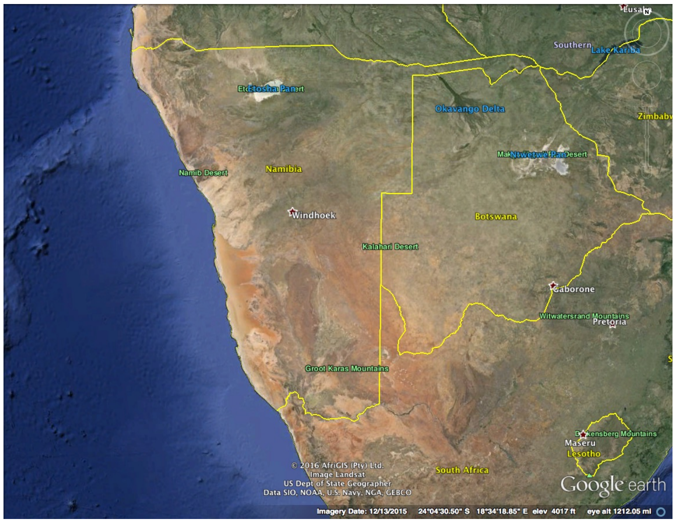

Figure 2.4 Physical Map of Namibia. [Google Earth, Map data: Google, AfriGIS (Pty) Ltd. Image Landsat, US Dept. of State Geographer, Data SIO, NOAA, US Navy, NGA, GEBCO]

2.3.4.2 Water

There is a very high demand for water in an incredibly arid area [Kohrs, 2012]. Water shortages and contamination are common issues for the communities near the mines [Koos, 2012]. Mining operations use water mainly for cooling, underground procedures like hydraulic drills and processing including flotation and leaching. In addition, the mine requires adjacent supporting infrastructure such as housing and transport, which also requires water [Ashton, 2001]. The UN Comprehensive Freshwater Assessment deemed Southern Africa as one of the most vulnerable regions for water-related problems. It classified Namibia's water resources as stressed and predicted them to become very vulnerable by 2015 [Pryor, 2009].

Namibia is trying to obtain funds for a new desalination plant in order to support its mining operations, which are expected to require 97Mm^3 by 2015 (30Mm^3 more than 2008) [Puigmal, 2011]. For instance, one mine, Trekkopje, requires approximately 20 million cubic meters per year of fresh water. The 55,000 m^3/day Trekkopje seawater desalination plant for Areva Resources Namibia (Pty) Ltd will help to reach this demand. It was built by a South African desalination specialist company Keyplan and utilizes high-efficiency TM820F-400 and TM820E-400 membrane elements produced by Toray Membrane USA, Inc. After passing through these membranes, the water contains less than 750 milligrams per liter (mg/L) salinity and less than 1.75-mg/L boron while operating at relatively low membrane feed pressures. The desalination plant will produce water for heap leaching of uranium at the Trekkopje mine. Additionally, some of the water will also be for potable uses at the mine [Pryor, 2009].

The mines use the underground water of the Swakop and Khan Rivers due to its lack of salinity in comparison to the seawater. If this usage is not monitored properly, there are concerns that the rivers will be depleted due to mining activities [Kohrs, 2012]. LHU is deemed to have water issues, water scarcity, and impacts on the environment but they only have a closure plan without a closure fund. Other mines in the area also have the same water concerns (Rossing, Aussinanis, Ripnes, Trekkopje, Marcenica, Etango, Omahola, and Valencia) but only one, Rossing, has a closure plan and fund [Kohrs, 2012].

In 2006, Rossing used 3.3 million cubic meters of water. This is 28% of the water usage for the entire coast. NamWater can only provide enough water for Paladin's Langer Heinrich mine, which uses 1.5 million cubic meters yearly. Other, later uranium mines must build desalination plants to meet their demand such as the Trekkopje mine as it demands 25 million cubic meters per year.

LHU gets water from Namibian Scheme Water (NamWater), a bore field; runoff water collected from the mine pits, and supernatant recovery from the tailings storage facilities. Water recycling includes the tailings storage facilities and recovery bore holes/trenches, and the treated effluent from the sewage treatment plant. [Paladin Energy, 2012] Open pit mines usually create more particulate emissions because they are open to weather effects. Tailings at uranium mines are generally covered with water to keep the radon and radioactivity under control. Re-vegetation is also recommended in order to control erosion [Nilsson, 2008].

In the entire uranium mining process, the majority of water and land is used for extraction and conversion compared to enrichment, fuel fabrication and transportation. These two steps utilize much more water: 132.1 L/MWh versus 1.23 L/MWh for the last three steps. Extraction and mining also involves the largest amount of land use, 7.512×10^{-3} m2/MWh compared to 1.43×10^{-4} m2/MWh. The previous value includes a mix of mining technologies which was approximately as 23% open pit, 41% underground, and 26% in-situ leaching. [Schneider, 2010] The water source types and amounts used at LHU are provided in Table 2.4.

Table 2.4 Water Usages for Langer Heinrich's Uranium Mine. [Paladin Energy, 2012]

Source	**Water Withdrawn 2011/2012 (m^3)**
Surface Water	0
Groundwater	231,000
Rainwater	234,000
Waste Water	0
Municipal Water Supplies	1,522,000
Total	1,987,000

2.3.4.3 Energy

Water used for various mining processes takes a tremendous amount of energy as well. There are innate energy costs for many hydraulic processes including purification, extraction, heating, etc. Known impacts on marine life are through the returned brine from the desalination plants and the water used for cooling, which returns at higher temperatures [Martin, 2012].

In the entire uranium mining process, the majority of energy is used for extraction and conversion compared to enrichment, fuel fabrication and transportation. This is a total of 34.3×10^{-3} GJ/MWh compared to 3.56×10^{-3} GJ/MWh. Extraction and mining involves the largest amount of carbon dioxide emissions, 2.23 kg of CO_2/MWh compared to 0.511 kg of CO_2/MWh, as well. The previous values included a mix of mining technologies which was approximately as 23% open pit, 41% underground, and 26% in-situ leaching [Schneider, 2010].

Energy requirements are expected to increase too. Electricity demand by uranium mining alone may reach 200 MW by 2015. This is extensive because the demand for the entire country, as of 2010, was 564 MW [Puigmal, 2011]. A study was done in 2009, determining the water and power use at full production of the mines in Namibia. The total was approximately 250 MW of power and 59 Mm^3 of water [Swiegers, 2009]. Another study found that Rossing's uranium mine utilizes 863 cubic meters of water and 354 GJ of energy per ton of U_3O_8 produced [Mudd, 2007]. This is quite large for a mining operation and could probably be reduced if it is organized more effectively. Major current issues include fragmented and incomplete legislation, absence of uniform environmental standards, mining in nature parks, and the extensive cumulative environmental/social/health impacts [Swiegers, 2009].

The future demand of Namibian uranium mines will be between 150 and 200 MW [Kohrs, 2012]. Namibia can produce, as of March 2012, 393 MW but has a peak demand of 611MW (for 2011) so it must import power from South Africa. Namibia's NamPower makes 240 MW via hydro, 132MW from coal and 21MW from distillate technology. This gives it an energy mix of 61% hydro, 34% coal and 5% distillate. The South African company Eskom makes approximately 218MW of Namibia's electricity using a mix of 5% hydro, 86% coal, 4% nuclear and 5% distillate. [SAPP, 2012] LHU, for example, uses mainly non-renewable energy sources for its processes. These sources and total consumption can be seen in Table 2.5.

Table 2.5 Energy Consumption and Fuel Usage for LHU. [adpated from Paladin Energy, 2012]

Energy Consumption	2011/2012
Total Direct Energy Consumption	1004 TJ
Total Indirect Energy Consumption	346 TJ
Breakdown of Fuel Usage:	
Diesel – Power Generation	51,596 L
Automotive Diesel	20,750,225 L
Automotive Petro	31,2000 L
Heavy Fuel Oil	6,424,744 L
Emulsion (blasting)	6,693 tons

2.4 Life Cycle Analysis

2.4.1 Need for Life Cycle Analysis

In 2010, a Strategic Environmental Assessment (SEA) was conducted for the Ministry of Mines and Energy (MME). It provides advice on how to avoid excessive negative cumulative impacts. Three scenarios were studied [Kohrs, 2012]. Since uranium mining creates short-term income but is associated with long-term impacts, a very careful study is needed. The SEA has conducted EIAs and has incorporated the main suggestions of the Strategic Environmental Assessment (SEMP) into the Environmental Management Plans (EMPs) for two new uranium mines [Dalal-Clayton, 2012].

2.4.2 Previous LCA Studies

A Life Cycle Analysis (LCA) is also referred to as a cradle to grave methodology as it "is an ISO 14000 recommended tool used to assess the environmental and social impact of a product throughout its useful life from its start as a raw material to disposal". Since the life of uranium starts at mining, this is an essential part of the process for the nuclear fuel cycle. An LCA is a good method to evaluate environmental performance [Adey, 2011]. Previous LCA studies of mines can be found in Appendix C.

The goal of an LCA is to quantify the environmental impacts associated with input and output flows per functional unit. LCAs are essential for the plan and design of uranium mines because environmental impacts must be taken into account.

The main steps for open pit mining, used for an LCA, are shown in Figure 2.5. In terms of mining types, surface mining causes fewer issues than underground due to having less processes and less necessary removal energy. On the other hand, underground mines are easier to abandon and require less remediation. Underground mines are also more hazardous for workers but less unsightly for the surrounding area. The emissions from LHU are provided in Table 2.6.

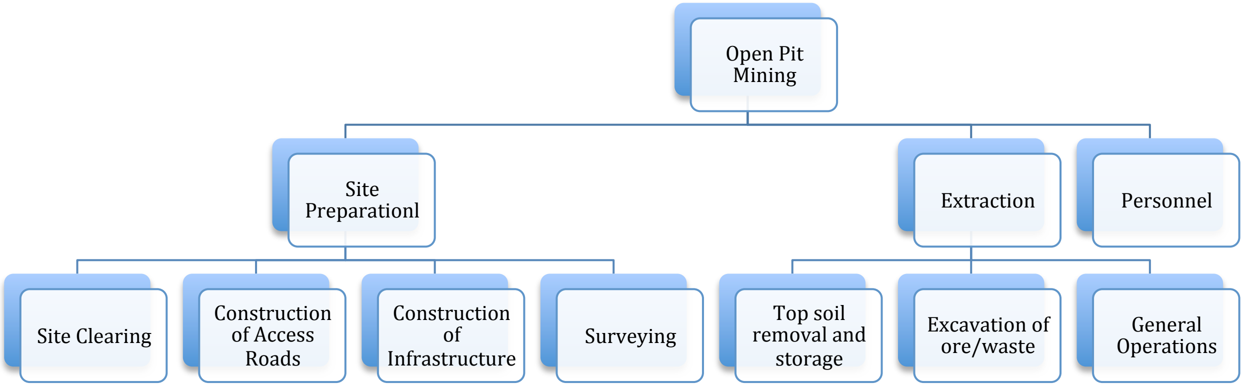

Figure 2.5 Major Steps for an LCA Performed on Open Pit Mining.

Table 2.6 Emissions from Mining Steps at the LHU. [adapted from Paladin Energy, 2012]

Source	Emissions in 2011/2012 (tons CO2)
Diesel for Generating Heat and Power	140
Automotive Diesel	56,198
Automotive Petrol	71
Heavy Fuel Oil for Heating	18,080
Emulsion	1,137
Total Direct Emissions	75,626
Total Indirect Emissions (Public Electricity)	93,512
TOTAL	169,138

As one can see, the emissions for the LHU mine are mainly due to diesel and heavy oil. It also has increased from 2010 to 2012, due to an increase in output but it would be extremely beneficial to utilize less energy for economic and environmental reasons. The majority of the energy is used for processing so advancing their technology may help alleviate this problem.

CHAPTER 3: METHODOLOGY

3.1 Introduction to Life Cycle Assessment

A life cycle assessment has four parts as set by the ISO 14040 standards. These include:

1. Defining Goal and Scope
2. Analyzing Inventory including inputs and outputs
3. Assessing the impact
4. Interpreting the results

[International Organization for Standardization, 2006]

SimaPro, a life cycle analysis program, can be used for uranium mining life cycle analyses as the unit processes for uranium mining are included in the inventory databases within it [Prouty, 2016]. The data of uranium mines in the SimaPro database was used and additional LHU data was added.

3.2 Goal and Scope

The goal of the LCA is to quantify environmental impacts of the LHU mining with a focus on energy and water such that they can be compared to another mine, McArthur River, because it has a different extraction process and does not exist in a water deprived area. The system boundary includes the mining and milling processes and is provided in Figure 3.1. The functional unit is 1.00 kg of natural uranium as outputted by the LHU mine.

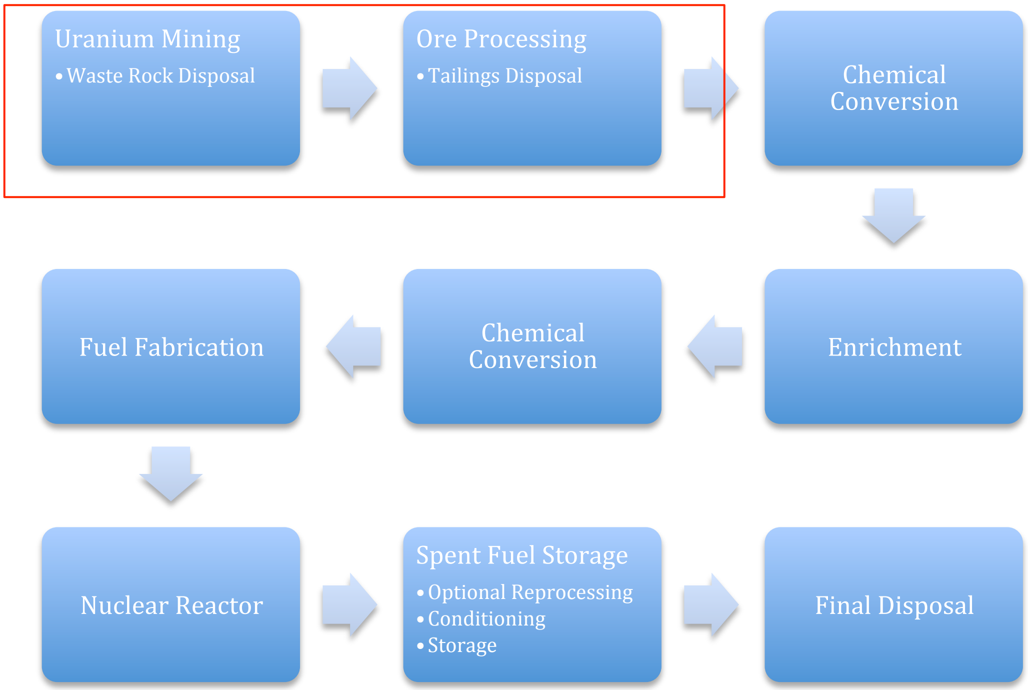

Figure 3.1 Uranium Mining Process with System Boundary For this Study

3.3 Inventory Analysis

Since the uranium mining processes contained in SimaPro are based on European data, some inputs had to be approximated using LHU specific information. For instance, the correct land type did not exist in the SimaPro database. LHU's mine is located in a national park that is a protected area of the Namib dessert called the Namib Naukluft Park. The closest available option in SimaPro is pasture and meadow because the area requires clearing of foliage and is a protected, important area. Additionally, the land estimate is approximately 1 to 2 square kilometers so the average of 1.5 square kilometers was used in the study.

The specific information from the LHU mine is shown in the Tables 3.1 – 3.4. The rest of the input was approximated using the natural uranium unit process for an open pit in SimaPro. The total output of the LHU mine for 2012 was 8,944,111 tons of ore, which was then milled to create 3,297,586 tons of yellowcake. Each SimaPro process was normalized to one kilogram for the mining and milling processes respectively. The mining process was then contained within the milling process so both were combined.

Additionally, only the total yearly energy and water input is available at the LHU mine so assumptions had to be made in order to determine how much of each input was used for mining versus milling. Since heavy fuel oil (HFO) is used for generators, heaters, boilers, furnaces, kilns, and ship steamers, it was assumed to be used only in milling. The allocation of diesel consumption was based on the data from Kunakemakorn (2011), which were found to be 11% for mining and 89% for milling (with values of 57.7 MJ and 483 MJ used at their mine). The diesel consumption for LHU was then calculated to be 18.975MJ for mining and 153.525MJ for milling. Finally, the allocation for water consumption was based on the ratio used in SimaPro for the basic mining and milling cycles which is 6:1 for mining: milling in an open pit mine.

For milling, the assumption was also made that excess alkaline solution is necessary to ensure the contact between alkaline solution and the ore particles due to the heap leaching process. The alkaline input is not available from the LHU mine and the alkaline excess ratio was estimated based on the acid milling process in SimaPro since it also used the heap leaching process. The acid excess was estimated using actual acid input in SimaPro and the theoretical acid requirement calculated from Equation 1. It was estimated that the acid excess is approximately 32 times the theoretical acid requirement. The alkaline (carbonate) input was then estimated using the excess ration (~32) and the theoretical alkaline requirement calculated from Equation 2. Since bicarbonate was also involved, the ratio of 1 mole carbonate: 2 moles bicarbonate was used to calculate the total alkaline consumption as carbonate [Maul, 2014].

Acid leaching: $UO_2^{+2} + 3SO_4^{-2} \rightarrow [UO_2(SO_4)_3]$ Eqn 1

Alkaline leaching: $UO_3 + Na_2CO_3 + 2NaHCO_3 \rightarrow Na_4UO_2(CO_3) + H_2O$ Eqn 2

[Weil, 2012]

Table 3.1 Input Data for the LHU Mining Process in SimaPro per Functional Unit.

Inputs from nature			
Transformation, from pasture and meadow	0.00000056	m^2	1.5 m^2 total
Transformation, to mineral extraction site	0.00000056	m^2	1.5 m^2 total
Occupation, mineral extraction site	4	m^2	from SimaPro
Uranium, in ground	1.05	kg	from SimaPro
Water, unspecified natural origin	0.3335	m^3	from LHU
Inputs from technosphere			
Diesel, burned in building/GLO U	4.088E-07	MJ	from LHU
Blasting/RER U	0.26	MJ	from SimaPro
Transport, lorry>16t, fleet average/RER U	7.23	kg	from SimaPro
Transport, freight, rail/RER U	1.37	tkm	from SimaPro
Electricity, hard coal, at power plant/CN U	6306.6	kWh	approx. from LHU
Electricity, hydropower, at power plant/RNA	3761.83	kWh	approx. from LHU
Electricity, diesel, at power plant/RNA	553.21	kWh	approx. from LHU
Electricity, nuclear, at power plant/UCTE U	276.61	kWh	approx. from LHU
Electricity, natural gas, at power plant/ASCC U	165.96	kWh	approx. from LHU

Table 3.2 Output Data from the LHU Mining Process in SimaPro per Functional Unit.

Outputs - Emissions to Air			
Particulates, > 10 um	0.056	kg	from SimaPro
Radon-222	130000	kBq	from SimaPro
Uranium alpha	0.094	kBq	from SimaPro
Outputs - Emissions to Water			
Aluminum	0.0031	kg	from SimaPro
Ammonium, ion	0.0085	kg	from SimaPro
Arsenic, ion	0.000093	kg	from SimaPro
Barium	0.0019	kg	from SimaPro
Cadmium, ion	0.000093	kg	from SimaPro
Chloride	0.86	kg	from SimaPro
Iron, ion	0.034	kg	from SimaPro
Lead	0.018	kg	from SimaPro
Magnesium	0.11	kg	from SimaPro
Manganese	0.069	kg	from SimaPro
Molybdenum	0.0016	kg	from SimaPro
Nitrate	0.0021	kg	from SimaPro
Selenium	0.00019	kg	from SimaPro

Table 3.2 (Continued)

Sulfate	48	kg	from SimaPro
Suspended solids, unspecified	2.1	kg	from SimaPro
Vanadium, ion	0.0065	kg	from SimaPro
Zinc, ion	0.0012	kg	from SimaPro
Radium-226	5000	kBq	from SimaPro
Thorium-230	460	kBq	from SimaPro
Uranium alpha	220	kBq	from SimaPro

Table 3.3 Input Data for the LHU Milling Process in SimaPro per Functional Unit.

Inputs from nature			
Transformation, from pasture and meadow	0.00000056	m^2	1.5 m^2 total
Transformation, to dump site	1.96	m^2	from SimaPro
Occupation, dump site	2.96	m^3	from SimaPro
Water, unspecified natural origin	0.0941	m^3	from LHU
Materials/fuels			
Diesel, burned in diesel-electric generating set/GLO U	0.00005734	MJ	from LHU
Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	0.0001977	MJ	from SimaPro
Ammonia, liquid, at regional storehouse/RER U	0.9	kg	from SimaPro
Ammonium sulfate, as N, at regional storehouse/RER U	0.106	kg	from SimaPro
Chemicals inorganic, at plant/GLO U	0.26	kg	from SimaPro
Chemicals organic, at plant/GLO U	0.315	kg	from LHU
Ethylenediamine, at plant/RER U	0.012	kg	approx. from LHU
Soda, powder, at plant/RER U	2.5	kg	approx. from LHU
Sodium chlorate, powder, at plant/RER U	1	kg	approx. from LHU
Sodium chloride, brine solution, at plant/RER U	2.5	kg	approx. from LHU
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	0.026	kg	approx. from LHU
Sulfuric acid, liquid, at plant/RER U	0	kg	approx. from LHU
Transport, lorry >16t, fleet average/RER U	6.3	tkm	approx. from LHU
Transport, freight, rail/RER U	32	tkm	approx. from LHU
Uranium mill/US/I U	0.000000135	p	approx. from LHU
Uranium natural, at open pit mine/RNA U	1.05	kg	approx. from LHU
Electricity, nuclear, at power plant/UCTE U	2517.5	kWh	approx. from LHU
Electricity, hydropower, at power plant/AT U	34238	kWh	approx. from LHU
Natural gas, burned in power plant/WECC U	1510.5	kWh	approx. from LHU
Electricity, hard coal, at power plant/CN U	57399	kWh	approx. from LHU
Sodium carbonate from ammonium chloride	25.2158	kg	approx. from LHU

Table 3.4 Output Data from the LHU Milling Process in SimaPro per Functional Unit.

Emissions to air			
Aldehydes, unspecified	0.00088	kg	approx. from SimaPro
Ammonia	0.0017	kg	approx. from SimaPro
Nitrogen oxides	0.017	kg	approx. from SimaPro
NMVOC, non-methane volatile organic compounds, unspecified origin	0.11	kg	approx. from SimaPro
Particulates, > 10 um	0.22	kg	approx. from SimaPro
Particulates, > 2.5 um, and < 10um	0.00088	kg	approx. from SimaPro
Sulfur dioxide	0.00023	kg	approx. from SimaPro
Lead-210	2	kBq	approx. from SimaPro
Polonium-210	3	kBq	approx. from SimaPro
Radium-226	1	kBq	approx. from SimaPro
Radon-222	150000	kBq	approx. from SimaPro
Thorium-230	1	kBq	approx. from SimaPro
Uranium-234	2.9	kBq	approx. from SimaPro
Uranium-235	0.14	kBq	approx. from SimaPro
Uranium-238	2.9	kBq	approx. from SimaPro
Emissions to water			
Aluminum	0.35	kg	approx. from SimaPro
Ammonium, ion	0.072	kg	approx. from SimaPro
Arsenic, ion	0.000081	kg	approx. from SimaPro
Barium	0.00011	kg	approx. from SimaPro
Beryllium	0.000014	kg	approx. from SimaPro
Calcium, ion	0.54	kg	approx. from SimaPro
Chloride	0.52	kg	approx. from SimaPro
Chromium, ion	0.00096	kg	approx. from SimaPro
Copper, ion	0.0002	kg	approx. from SimaPro
Cyanide	0.00000088	kg	approx. from SimaPro
Fluoride	0.00066	kg	approx. from SimaPro
Hydrocarbons, unspecified	0.0035	kg	approx. from SimaPro
Iron, ion	0.1	kg	approx. from SimaPro
Lead	0.0015	kg	approx. from SimaPro
Magnesium	0.01	kg	approx. from SimaPro
Manganese	0.015	kg	approx. from SimaPro
Molybdenum	0.0019	kg	approx. from SimaPro
Nickel, ion	0.0001	kg	approx. from SimaPro
Nitrate	0.0087	kg	approx. from SimaPro
Phosphate	0.00022	kg	approx. from SimaPro
Selenium	0.0016	kg	approx. from SimaPro

Table 3.4 (Continued)

Silver, ion	0.00000088	kg	approx. from SimaPro
Sodium, ion	0.04	kg	approx. from SimaPro
Sulfate	1.6	kg	approx. from SimaPro
Sulfide	0.000044	kg	approx. from SimaPro
Titanium, ion	0.0012	kg	approx. from SimaPro
Vanadium, ion	0.000018	kg	approx. from SimaPro
Zinc, ion	0.00052	kg	approx. from SimaPro
Carbonate	0.036	kg	approx. from SimaPro
Radium-226	1	kBq	approx. from SimaPro
Thorium-230	150	kBq	approx. from SimaPro
Uranium-238	4.85	kBq	approx. from SimaPro
Uranium-234	0.3	kBq	approx. from SimaPro
Uranium-235	4.85	kBq	approx. from SimaPro

The water from a well was used in SimaPro since that is the main source for NamWater to supply water to the mine. All of the electricity at LHU is from NamPower, which generates 39% of their power and purchases the rest from three other suppliers: 40% from ESKOM, 12% from ZESA, and 9% from ZESCO. Since the data for ZESA and ZESCO is unavailable and the majority of power supply is from NamPower and ESKOM, the energy mix is determined based upon the assumption of 50% from NamPower and 50% from ESKOM.

The electricity consumption was then allocated to mining and milling. The estimate for electricity was based on the percentages of 24% for underground mining and 13% for open pit mining, with the rest being milling [Schneider, 2013]. This produced totals of 5.136 x 10^{10} kWh for open pit mining and 2.696 x 10^{11} kWh for milling, which was then normalized to one kilogram of yellowcake and subdivided into energy sources as shown in Table 3.5.

Table 3.5 Electricity Mix for the LHU Mine for SimaPro Input per Functional Unit.

Electricity Source	Percent of total	Mining Amount (kWh)	Milling Amount (kWh)
Coal	57%	6306.6	57399

Table 3.5 (Continued)

Hydro	34%	3761.8	34238
Diesel	5%	553.2	5053
Nuclear	2.5%	276.6	2517.5
Natural Gas	1.5%	165.9	1510.5
TOTAL	100%	11064.1	100718

Each electricity source requires knowledge of the production efficiency. The coal plants were subcritical ones that were likely at about 34.8% efficiency, which is a Chinese power plant in SimaPro. Additionally, an Austrian company makes the hydro plant, so the Austrian hydroelectric plant efficiencies in SimaPro were used. The nuclear power plants depend on type. Since all of ESKOM's reactors are pressurized water reactors (PWRs), the nuclear power country profile with the maximum number of PWRs in SimaPro, 90%, was used. The world average for natural gas and diesel in SimaPro was utilized.

3.4 Impact Assessment

Two impact assessment methods were used in SimaPro. The first, ReCiPe, was used for general environmental impact evaluation as well as water depletion potential because it contains the main environmental impact indicators and also a water depletion indicator. Secondly, Cumulative Energy Demand was used for the energy assessment. This method subdivides energy use by type and life cycle stages. For both ReCiPe and Cumulative Energy Demand, the cultural perspective chosen was Hierarchist, which is the consensus model often used in scientific models. The other two options, Individualist, and Egalitarian, assume short term and long term respectively so Hierarchist is a perfect middle ground. The LHU mine is gradually taking environmental advice into account so the Egalitarian model is too pessimistic. On the other hand, the individualist one is too optimistic that technology can avoid many problems in the future.

3.5 Interpretation

The results from the LCA of the LHU mine are interpreted and the embodied water and energy use were compared to the direct water and energy use at the mine. The results are then compared to those at the McArthur River uranium mine in Saskatchewan, Canada. The McArthur River mine was chosen as a comparison because it exists in a less arid region. The McArthur River mine uses sulfuric acid and ammonia opposed to carbonate alkali leaching which is the LHU's extraction method. Additionally, the ore grades vary immensely with LHU's of 0.0519% [Heyns, 2013] and McArthur's of 12.75% uranium oxide [Kunakemakorn, 2011].

Uranium in the McArthur River deposit is located approximately 500 meters below the surface [Farquharson, 2009] while the deposit at LHU is on the surface. They both are approximately 80-85 km away from the nearest town, which is Swakopmund for LHU [Heyns, 2013] and Key Lake for McArthur River [Jamieson, 2000].

CHAPTER 4: RESULTS

4.1 Impact Assessment

As seen in Tables 3.2 and 3.4, emissions to the air from the mining and milling processes include mainly ammonia, nitrogen oxides, non-methane volatile organic compounds, lead, polonium, radium, thorium, uranium, and particulates greater than 10um. Major emissions to the water include many of the same as well as aluminum, calcium, chloride, hydrocarbons, iron. The resulting environmental impacts, using ReCiPe, are shown in Figure 4.2. Material and energy input as well as emissions at the LHU mine for mining and milling leads to various environmental impacts including human toxicity, fresh water eutrophication and toxicity, ionizing radiation, and marine eco-toxicity as shown in Figure 4.1.

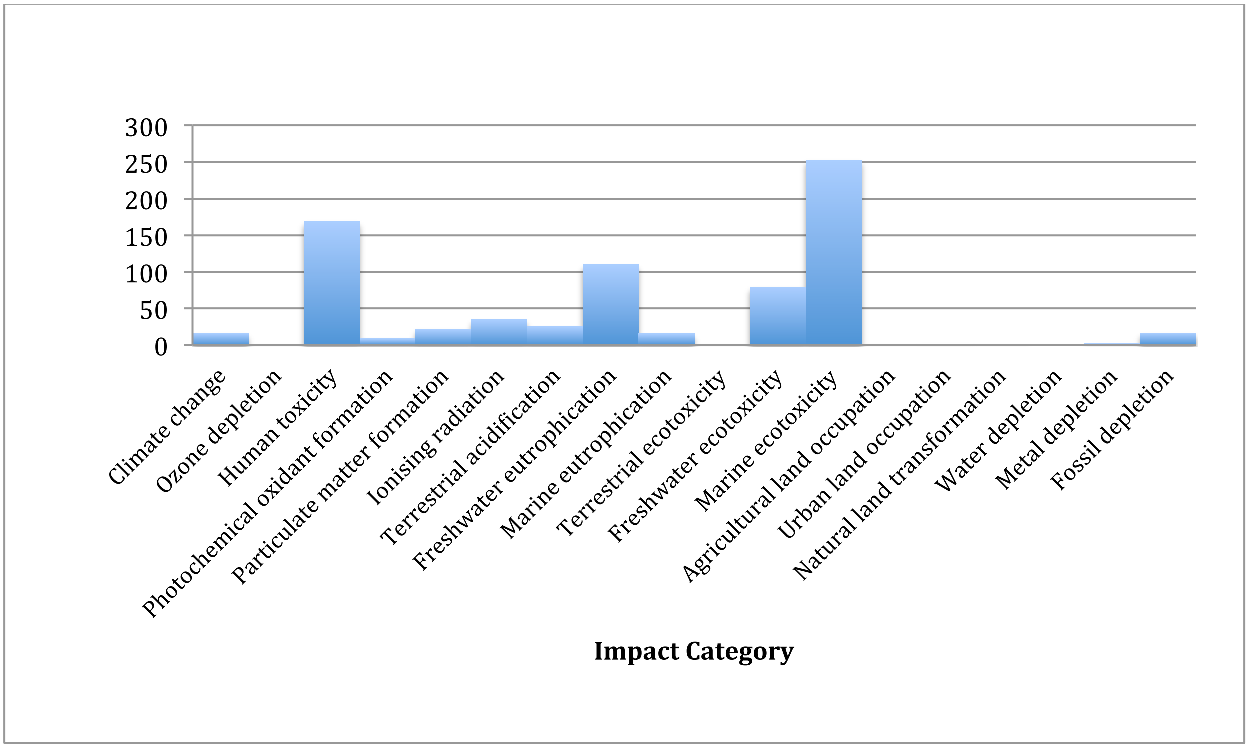

Figure 4.1 ReCiPe Impact Assessment Totals - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

The main impact categories are freshwater eutrophication, marine ecotoxicity and human toxicity. Figures 4.1-4.7 portray which process steps are responsible for these main impacts. As shown, the majority of impact is due to electricity consumption in both mining and milling, especially electricity generated from hard coal.

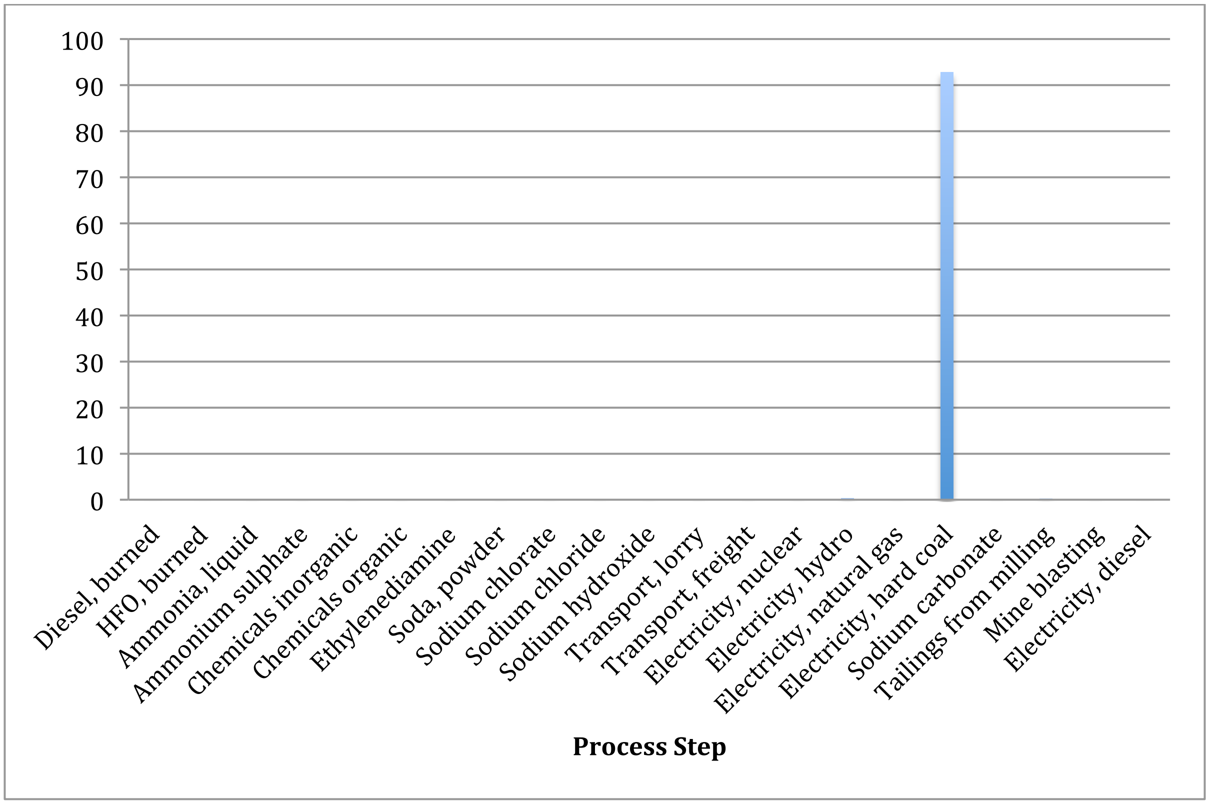

Figure 4.2 ReCiPe Impact Assessment of Freshwater Eutrophication by Process Step - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

In terms of freshwater eutrophication not including the contributions from electricity generated from coal, Figure 4.3 shows that hydro-electricity, tailings form milling, sodium carbonate, and nuclear electricity also cause freshwater eutrophication at the LHU mine.

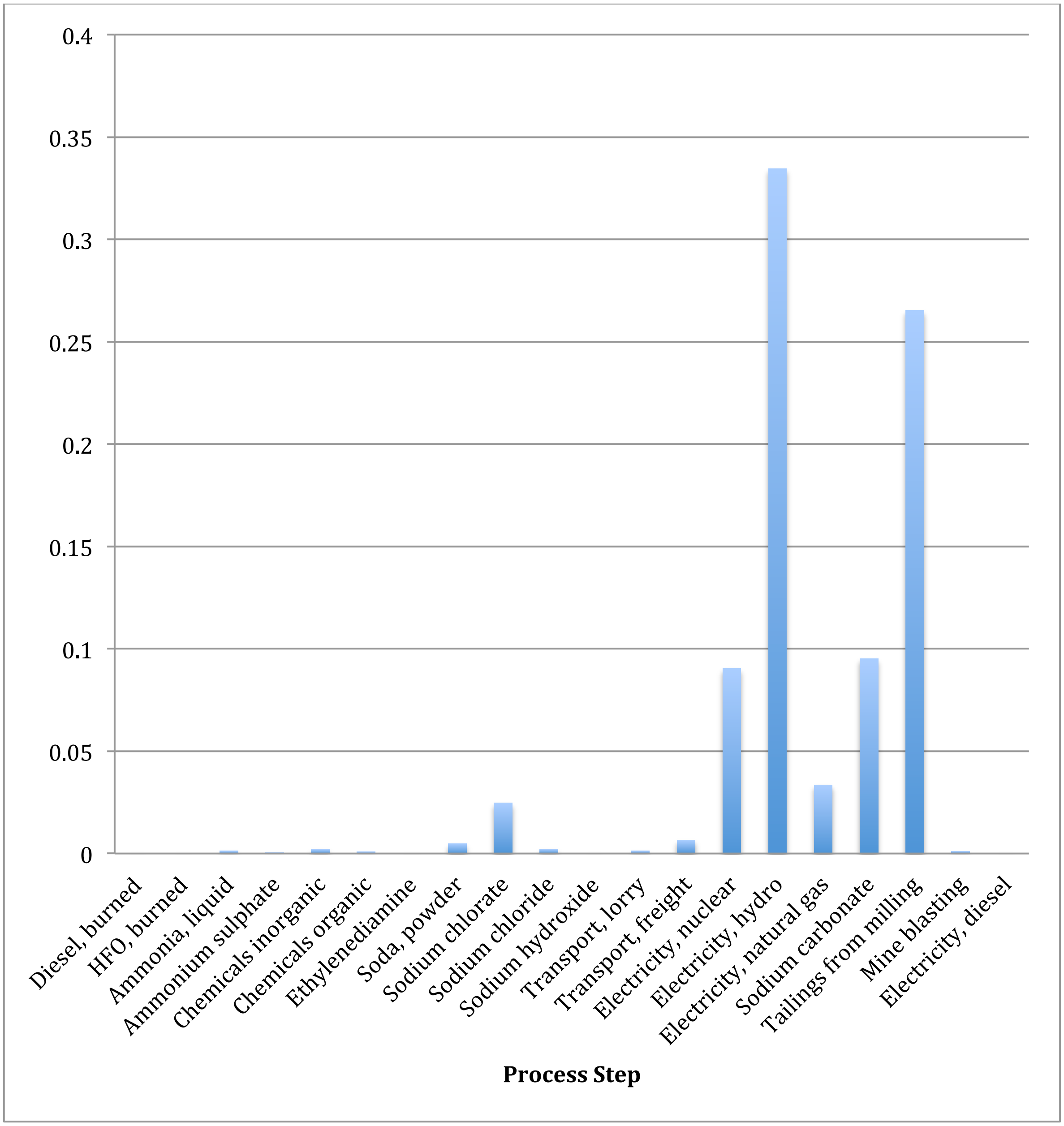

Figure 4.3 ReCiPe Impact Assessment of Freshwater Eutrophication by Process Step (Without Hard Coal Generated Electricity) - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

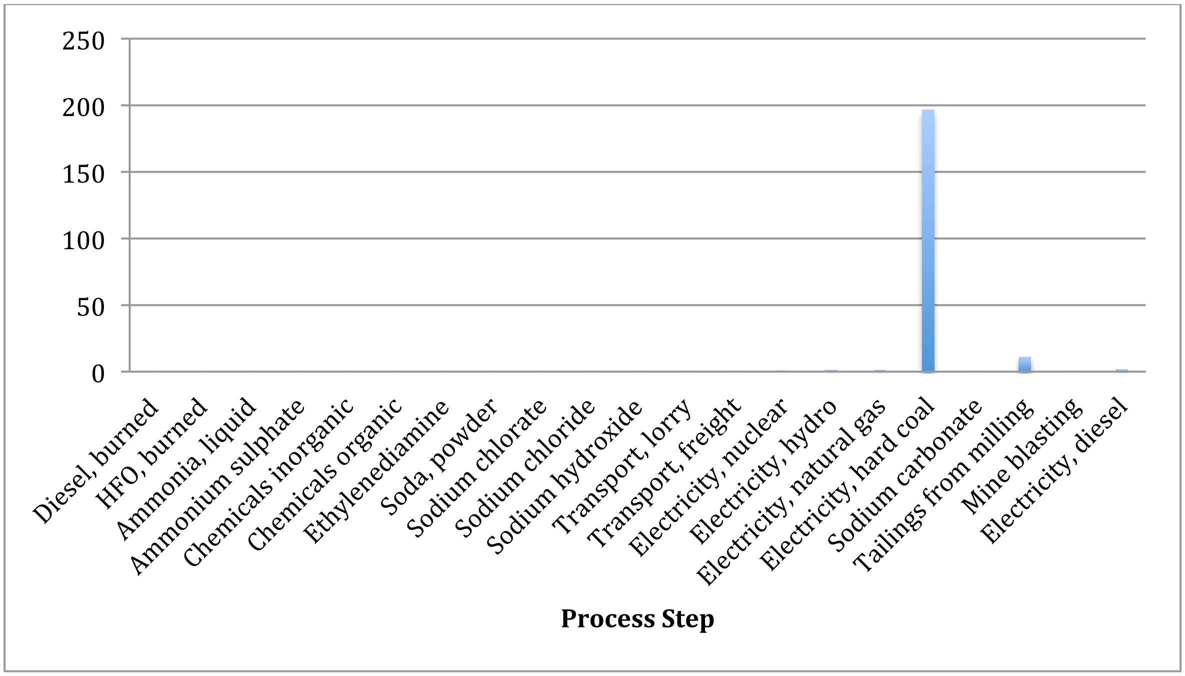

Figure 4.4 ReCiPe Impact Assessment of Marine Ecotoxicity by Process Step - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

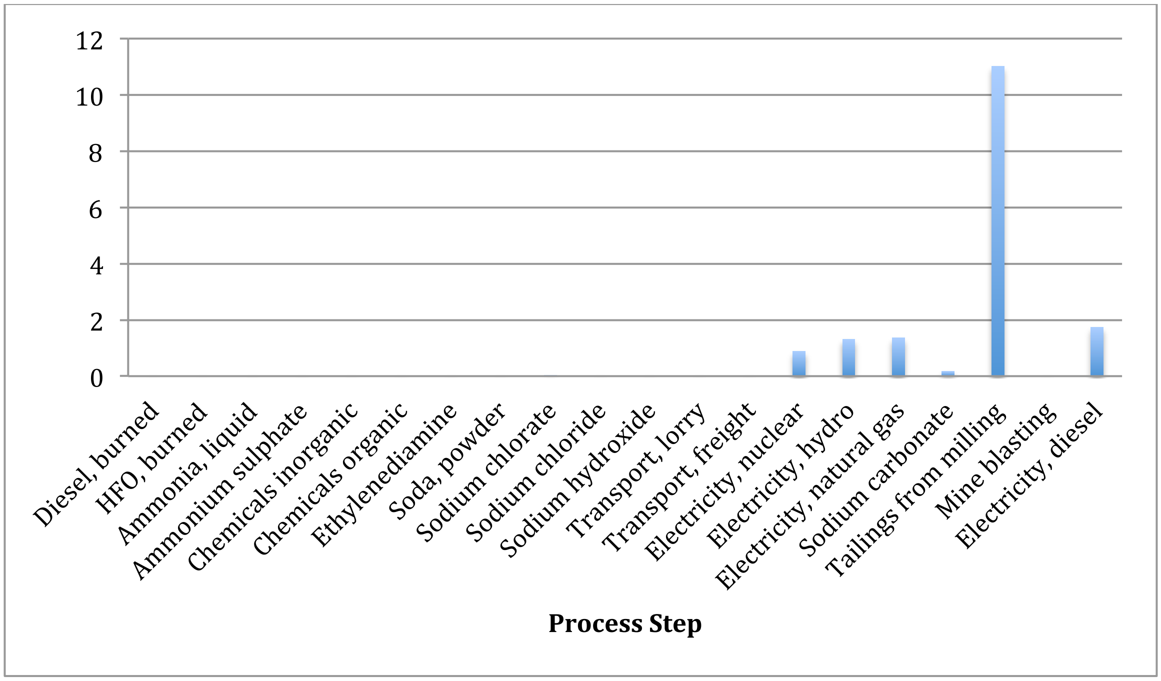

Figure 4.5 ReCiPe Impact Assessment of Marine Ecotoxicity by Process Step (Without Hard Coal Generated Electricity) - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

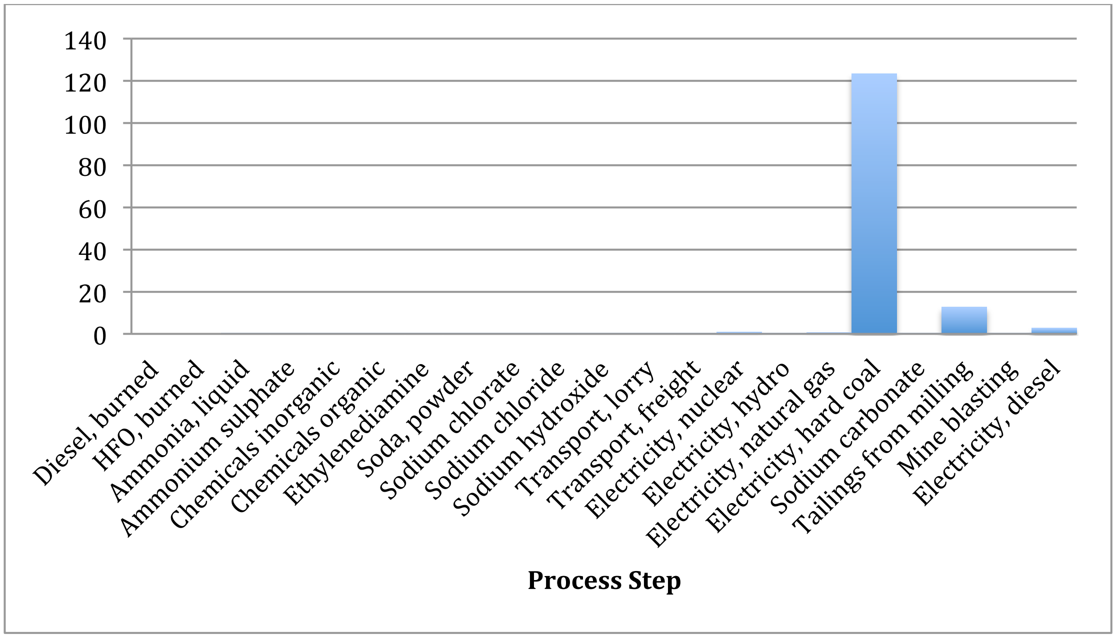

Figure 4.6 ReCiPe Impact Assessment of Human Toxicity by Process Step - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

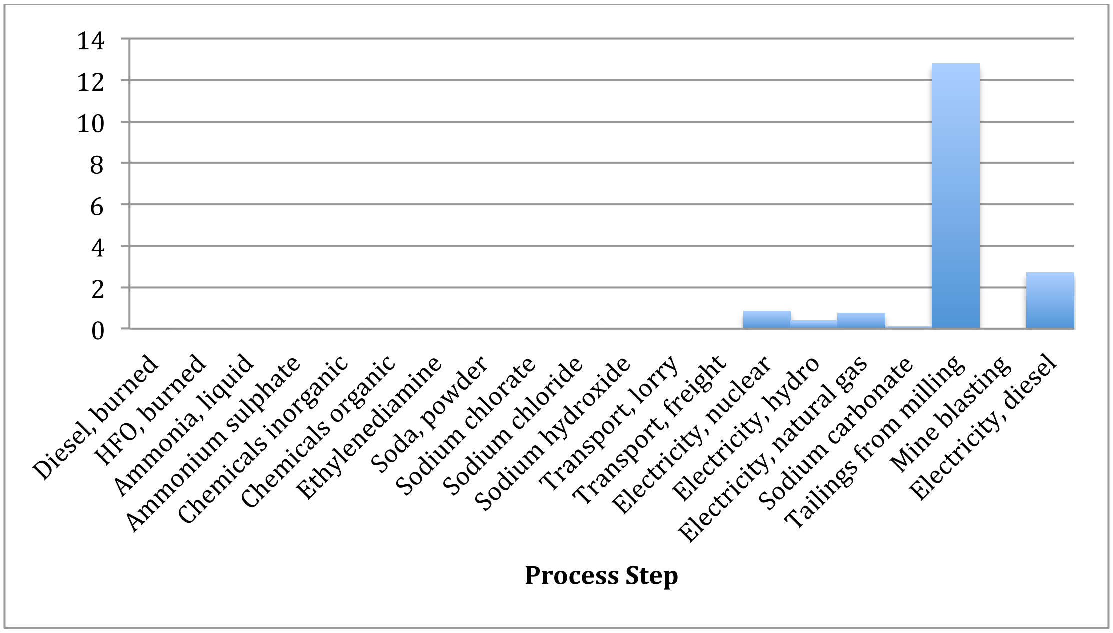

Figure 4.7 ReCiPe Impact Assessment of Human Toxicity by Process Step (Without Hard Coal Generated Electricity) - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

At the LHU mine in Namibia, the majority of the environmental impact comes from electricity use. Additionally, the LHU mine uses some heavy oil in the process, which is very inefficient and produces many pollutants. The major impact, as portrayed in Figure 4.4, is marine ecotoxicity coming mostly from the coal-based electricity used. The coal-based electricity also produces high levels of human toxicity as shown in Figure 4.6. The marine ecotoxicity and human toxicity coming from the milling tailings is also high as can be seen in Figures 4.3 and 4.5. The other electricity generation types, including nuclear, hydro, natural gas, and diesel contribute to marine exotoxicity and human toxicity as well.

4.2 Water

4.2.1 LHU Water Analysis

Since the LHU mine is in the desert of Namibia, water is a very important input. Currently, most water is provided by underground reservoirs or wells. However, it is important to note that LHU is planning to start obtaining water from a desalination plant soon as well. This will make the mine less reliant on water from cities and able to make their own potable water. It will also decrease transport costs and impacts but will likely increase those at the actual facility for the desalination plant. The total amount of water used by the mine in 2012 was 1.8 million cubic meters. This is a large volume but water is essential to many processes at the mine, especially in making the slurry of ore for processing as well as cooling and other aspects of the industrial processes.

As shown in Figure 4.8, the major contributor to water depletion is electricity produced from hard coal. Nuclear electricity also has high contributions to water depletion, portrayed in Figure 4.9, while the rest of the steps had a minimal water impact. The total amount of water depletion shown is 282.67 cubic meters per kilogram of yellowcake as determined by the LCA.

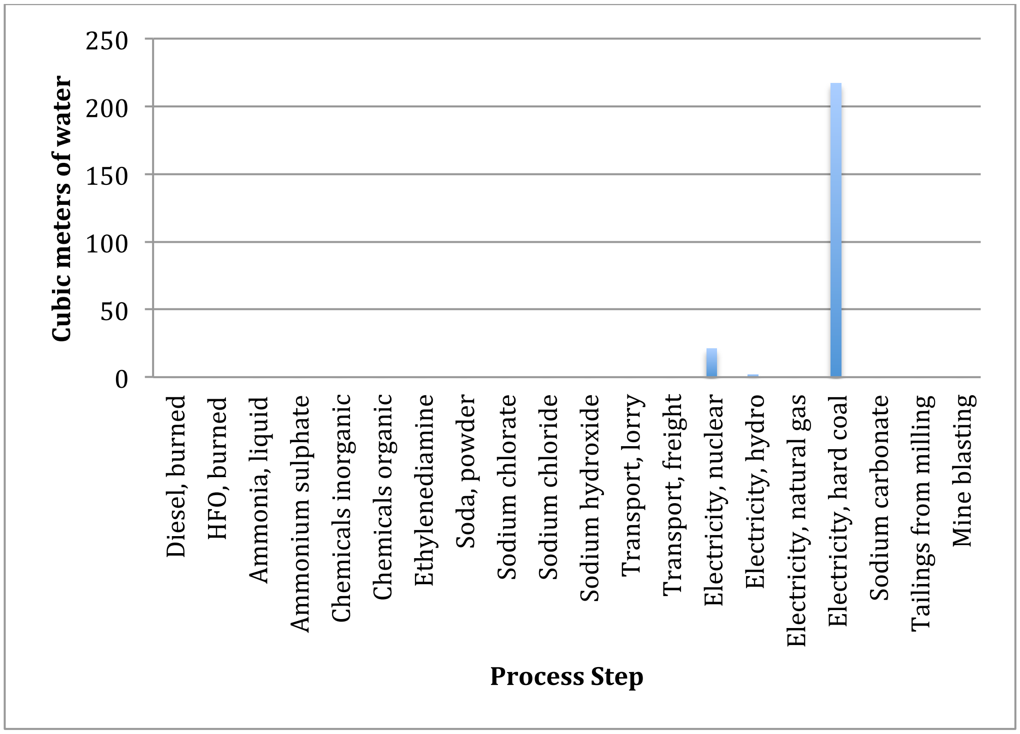

Figure 4.8 Water Depletion from ReCiPe - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

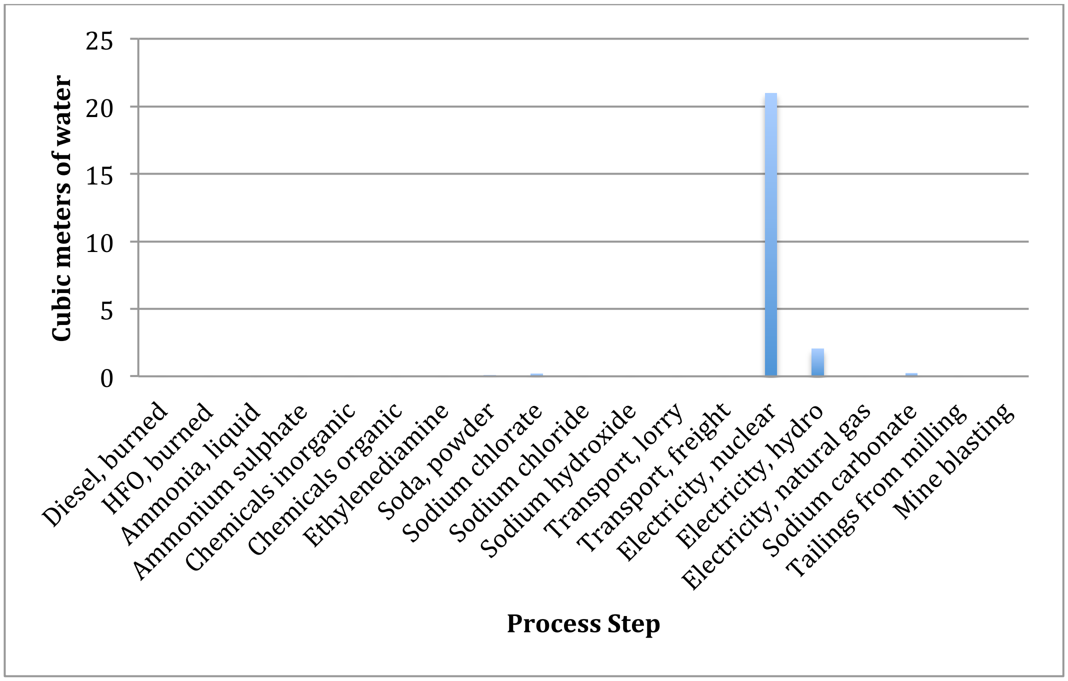

Figure 4.9 Water Depletion from ReCiPe (Without Hard Coal Generated Electricity) - Egalitarian Normalization of the LHU Mine in Namibia, 2012.

The economic value of water is an essential aspect to understanding its impact, especially in an arid place. Water is an especially important concern in Namibia as it receives less than the world average of 860mm annually and is considered ‘water stressed’. By 2025, Namibia is projected to face chronic scarcity [Jasparro, 2009]. Water is often cited as the single largest constraint to economic and infrastructure development in Namibia. Approximately 80% of Namibia’s land is classified as desert, arid, and semi-arid land. The majority of Namibia’s GDP depends on water in some way as they are mining, agriculture, fishing, and wildlife tourism. From the residual imputation method, the financial marginal value product of water comes to N$ 0.03 per m^3. The economic marginal value product is then found to be N$0.64 per m^3 [MacGregor, 2000].

In MacGregor, 2000, the financial marginal value product for water can be found to be N$0.03 per cubic meter while the economic marginal value product is N$0.64 per cubic meter. Based on the LCA results of 282.67 cubic meters of water needed for one kilogram of yellowcake, embodied water use per kilogram of yellowcake has a financial marginal value of N$8.48 and an economic marginal value of $N180.91 per kilogram of yellowcake. The mine should keep in mind that the cost of water is lower than its overall financial and economic marginal values. The amount the mine pays, per kg of yellowcake produced, is N$8.58 per cubic meter, which translates to N$2,425 and is actually much larger than the financial marginal value and the economic marginal value.

4.2.2 Comparison to Direct Water Use

The LHU mine is a perfect example of the importance of considering the embodied water use versus the direct water use at the site. The embodied water use, per kilogram of yellowcake, is 282.67 m^3, which is much larger than the direct water use of 5.459 E-4 m^3 per kilogram of yellowcake produced in 2012.

4.2.3 Comparison to Other Mines

As seen in Table 4.1, LHU mine's direct water use value of 0.5459 m^3 per ton of yellowcake is very small compared to the other mines.

Table 4.1 Water Usage of Other Mines. [adapted from Mudd, 2008]

Name of the Uranium Mine	Average Water Usage (Cubic meters / ton of yellowcake)
Ranger	**46.2**
Olympic Dam	**578**
Rossing	**868**
Cluff Lake	**365**
McLean Lake	**257**
Beverley	**8,207**

4.3 Energy

4.3.1 LHU Energy Analysis

Embodied energy is the energy required to make all components of the uranium mining chain. This includes everything from transportation to mining, processing to production. Data for mines does not usually account for embodied energy for required reagents such as sulfuric acid, lime, oxidants, solvents, etc. [Mudd, 2008]. The life cycle analysis on SimaPro for the LHU mine performed showed an excessive use of fossil fuels. This was from both the electricity and fuels burned on site for transportation and the mining process. Over 80% of the energy used was fossil fuels. The other portions of the energy profile included hydro and nuclear power. These are all shown in Figure 4.10.

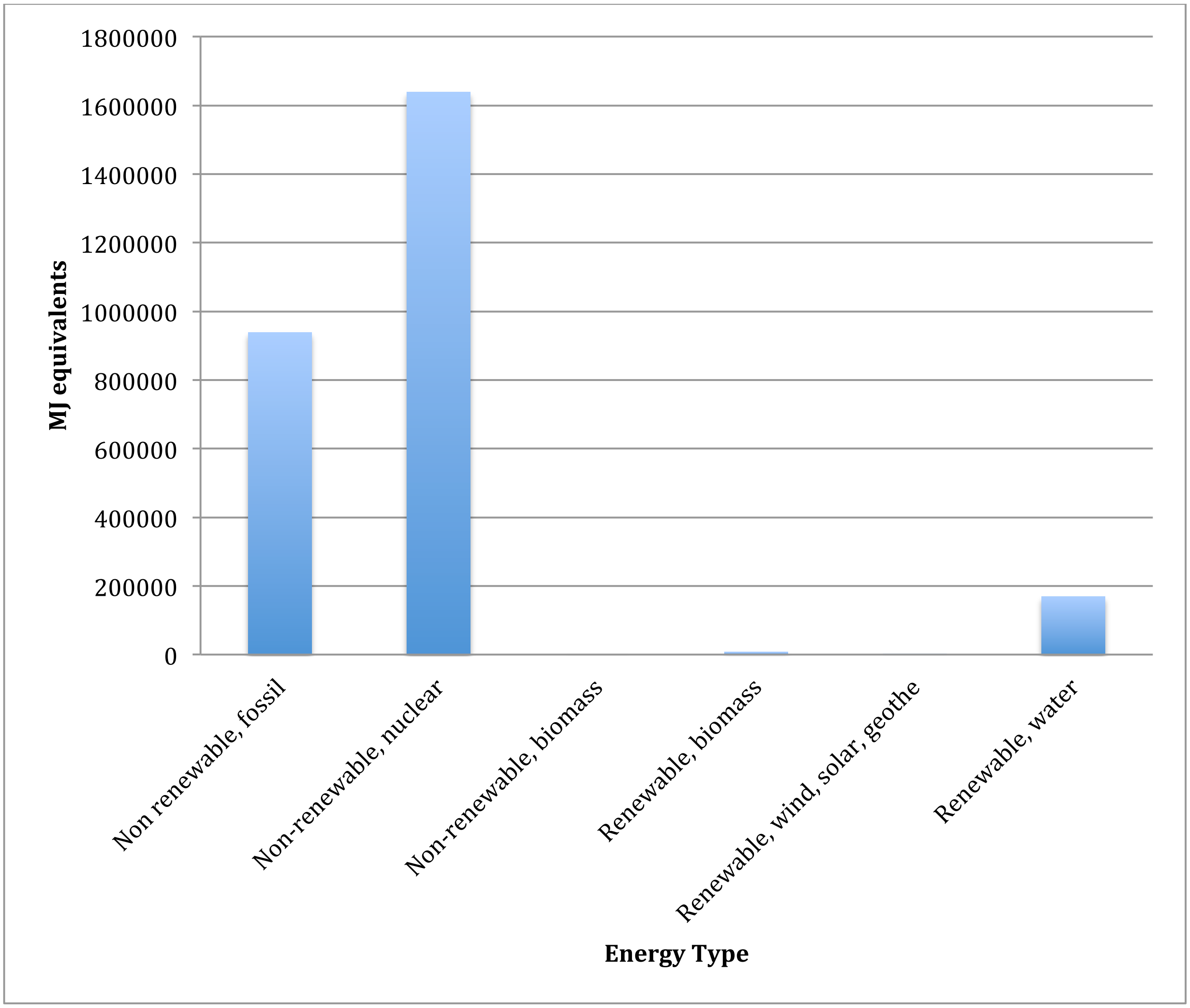

Figure 4.10 Cumulative Energy Weighting for the LHU Mine in Namibia, 2012.

Figure 4.11 shows a detailed graph of each type of energy used in mining versus milling. The figure shows that most of the energy was for the mining portion. The figure shows the major energies used are non renewable, nuclear energy at the uranium mine and non-renewable, fossil as hard coal. The process also uses a small amount of non-renewable, biomass energy, wind, solar and hydro/water electricity.

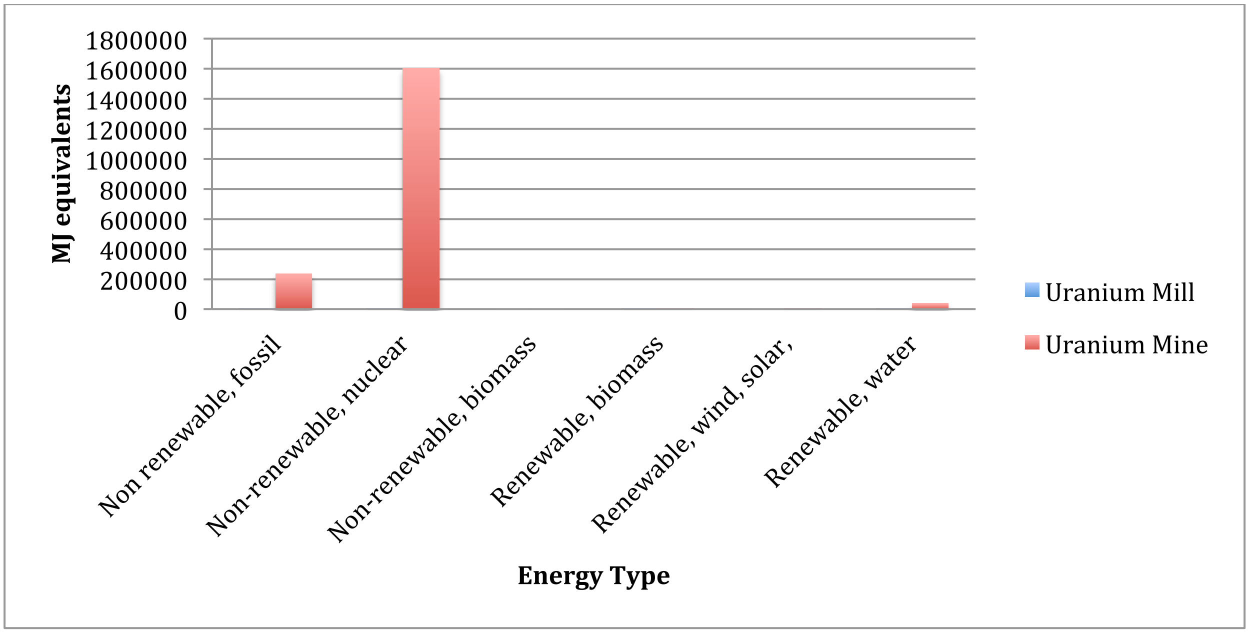

Figure 4.11 Breakdown of Cumulative Energy Demand for Mining versus Milling for the LHU in Namibia, 2012.

4.3.2 Comparison to Direct Energy Use

The direct energy use at the mine is much lower than the embodied energy. Direct energy use was 97.34 kWh of electricity and 5.9 E-5 kWh of diesel and HFO per kilogram of yellowcake while the embodied energy was 76,479 kWh per kilogram of yellowcake produced in 2012. This exemplifies the importance of utilizing LCA as a method to assess environmental impacts. This takes into account the entire off site generation as well as the production of the necessary supplies.

4.3.3 Comparison to Energy Usage at McArthur River Mine

Table 4.2 Diesel and Electricity for McArthur River Uranium Mine.

[adapted from Kunakemakorn, 2011]

Process		Amount
Mining	Diesel Consumption	57.7 MJ/t Ore
	Electricity Consumption	70.6 kWh/t Ore
Milling	Diesel Consumption	783 MJ/t Ore
	Electricity Consumption	18.6 kWh/t Ore
	TOTAL Diesel	840.7 MJ/t Ore
	TOTAL Electricity	89.2 kWh/t Ore

The diesel and electricity use at McArthur River Uranium Mine is shown in Table 4.2. As can be seen, the amount of diesel and HFO for mining and milling used at LHU (7.8465 E-5 MJ per ton of ore) is much lower than that at McArthur River mine (840.7 MJ) but LHU uses much more electricity per ton of ore (3.59 E4 kWh versus 89.2kWh). Perhaps this is because the LHU mine is further away from diesel sources or because the electricity is cheaper in Namibia. Additionally, the LHU mines uranium of a much lower ore grade, which likely creates more electricity use in the milling phase.

4.3.4 Comparison to Other Mines

Table 4.3 Energy Usage of Other Mines. [adapted from Mudd, 2008]

Uranium Mine	Average Energy Usage (GJ / ton of yellowcake)
Ranger	**191**
Olympic Dam	**1382**
Rossing	**276**
Cluff Lake	**356**
McLean Lake	**202**
Beverley	**198**
Niger	**204**
Cameco	**178**

The embodied energy of LHU is 2753.250 GJ/ton of yellowcake, which is much higher compared to the energy use of the other mines shown in Table 4.3. LHU uses extensive electricity, which leads to this a high-energy usage per ton of yellowcake produced.

CHAPTER 5: DISCUSSION

5.1 Environmental Concerns

The major environmental concerns for the LHU mine are the impacts associated with tailings, the mining, and the electricity usage. Compared to the other mines, the water usage is relatively low. On the other hand, the electricity use is extensive. The mine also caused removal of vegetation, in a protected area. In addition, residues from the mine can contain Radon-222 and other air and ground pollutants such as corrosive liquids, organics, and heavy metals. These can contaminate the groundwater as well.

5.2 Public Health Issues

In addition to environmental problems, mining can also lead to public health issues within local mining communities. Having a mine increases STIs including HIV/AIDS due to the transient nature of populations that tend to work for the mine. Mining also heavily impacts resource availability. This is, perhaps, most important when assessing water usage. Mining affects water in terms of both amount and quality, which can impact the health of the people living nearby. The increase in dust particles and other air pollution associated with mining is also critical. If tailings and processing waste is not dealt with appropriately, pollution from them, including radiation, can pose health risks.

Mining also affects sociological aspects of the surrounding area by changing local culture and economy. This is especially prevalent in Namibia where a local tribe, which remains very traditional in their way of life, is near to many of the mines including LHU. These people, the San (sometimes called Bushmen), are affected by the mine in that their culture can become altered or lost. Mining economies can lead to increased alcoholism as workingmen suddenly have money to spare and are often away from their families and communities. Mining has also created conflict over land and other resources such as water and energy. Additionally, land is taken which affects local land use such as herding and farming as well as tourism opportunities. This in turn causes wealth disparity that is especially noticeable due to the extremes of wealthy mine workers versus poor local farmers. The local prices, including food and medicine, often go above the amount local farmers and herders are able to pay.

In general, mining is also associated with a cycle of wealth and poverty. Initially, the development of a mine in a resource poor setting can result in improved local infrastructure, available commodities, and increased spending money ultimately enhancing the local economy. However, once the minerals are removed and the mine is no longer functioning, this period of wealth and population growth tends to be followed by a dramatic decline. Once the mine is closed, people are often left with no livelihood, especially those that migrated only to work at the mines.

Radiation is also an important public health concern associated with uranium mining. The world background dose of radiation is 2.4 mSv per year, more than half of which is due to radon. Single doses of 5000 mSv are fatal for half the exposed population and single doses of 10000 mSv are lethal within weeks. Occupational radiation doses can range from 1 mSv to 13 mSv in a year. Doses to the public vary from 0.003 to 0.1 mSv per year. Doses below 100 mSv are considered low-level doses [Nilsson, 2008]. Uranium can create ionizing radiation. This means that it can remove electrons from material and absorb the energy so ions are produced. Ionizing radiation can change the structure of molecules and DNA within body cells. If the body's cells are not correctly repaired, this can develop into potential cancer cells. Uranium radiation is only a concern when it is ingested or inhaled [Nilsson, 2008]. When uranium is ingested or inhaled, it can be deposited in organs such as kidneys, lungs, brain and bone marrow. It then emits alpha radiation, which can severely damage surrounding tissue. Uranium can be resorbed from the stomach and accumulate in bones. This can lead to leukemia later in life [Winde, 2010]. Due to its hazardous effects, alpha particles are represented with a factor of 20 in dosimetric calculations to maintain their higher toxicity than beta and gamma particles [Winde, 2010]. Additionally, Uranium is known to be an endocrine disruptive compound (EDC) meaning that it mimics estrogen in the body and could lead to fertility problems as well as reproductive cancers [Winde, 2010].

As the public health and socioeconomic issues associated with mining are so complex, deep rooted in the local culture, and entrenched in poverty, additional studies should focus on better understanding the true cost-benefit of mining while elucidating factors that can help to foster positive growth and sustainability. This is particularly vital in areas such as Namibia that are experiencing the rapid proliferation of mines and the resulting impacts on local economies, infrastructures, cultures and communities.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objective of this study was to evaluate the environmental effects of uranium mining. Since mining's major inputs are water and energy, these were the focus of the LCA of the process to create one kilogram of yellowcake. A comparison between direct and embodied water and energy was utilized to portray the importance of a life cycle analysis. Finally, the water and energy usage was compared to that reported for other global mines. The related hypothesis was that the LHU mine has high energy and water embodiment for its output of yellowcake due to its arid location and intensive processes. This embodiment was expected to be high in comparison to other mining sites worldwide for which evaluation data was available in literature.

SimaPro was used to perform the life cycle analysis for mining and milling at LHU. Within SimaPro, ReCiPe showed environmental impacts including water depletion. The main environmental impacts were found to be marine ecotoxicity, human toxicity, freshwater eutrophication, and freshwater ecotoxicity. These overwhelmingly came from hard coal electricity generation and the uranium mining process. Lower levels of marine ecotoxicity and human toxicity were due to milling tailings. Water depletion was mainly due to hard coal electricity and uranium mining as well. Additionally, nuclear generated electricity also caused some water depletion. Cumulative Energy Demand was used to understand the embodied energy. Weighting portrayed the main energy used, in MJ equivalents, was nuclear power, followed by fossil fuels then hydropower. The majority of the energy was used for uranium mining with some also used for the hard coal electricity and small amounts for nuclear and hydropower generation.

When direct values for water and energy were compared to the embodiment values, they were shown to be much smaller. The direct value for water, per kilogram of yellowcake, was 5.459

E-4 m^3 while the embodied value from the LCA was found to be 282.67 m^3. The direct energy values were 97.34 kWh of electricity and minimal diesel and HFO (5.9 E-5 kWh) per kilogram of yellowcake. The embodied value, 76,479 kWh per kilogram of yellowcake, was three magnitudes larger. Both the water and energy values portray the importance of using LCA to assess environmental impact.

Water usage at LHU, per ton of yellowcake, was shown to be much smaller than the use at other mines. Since the facility is located in the middle of the desert, perhaps they focus on minimizing water usage. On the other hand, energy usage at LHU was shown to be much more extensive. Although the amount of energy generated on site (from HFO and diesel) was lower than at McArthur River Mine, the electricity used, generated off site, was three magnitudes larger. This could be due to the LHU mine's isolated location as well as the lower cost of electricity in Namibia. Additionally, the LHU mine has uranium deposits of a much lower grade so it likely requires more energy throughout the milling process. The energy usage at LHU, per ton of yellowcake, was fond to be much larger than that at the other comparison mines as well.

Limitations of this study include the assumptions that were necessary to use SimaPro for the LCA. Many values used in the analysis, including all emissions data, were global or European estimates contained within SimaPro. Another limitation was the assumptions for electricity generation methods since NamPower uses energy from four difference sources, two of which had a dearth of information. Finally, determining which inputs were used for mining versus milling required estimation because only the total values were given. This is due to a lack of specific information from the mine. Additionally, inputs had to be adapted for the alkaline leaching process since SimaPro contained only acid leaching.

6.2 Recommendations

Recommendations for the mine include minimizing electricity usage as much as possible as well as maintaining better records so future LCAs can be done more accurately. Additionally, the countries that are providing the electricity, mainly South Africa and, Namibia but also Zambia and Zimbabwe, should attempt to develop more alternative energies including hydro, biomass, solar, and wind. Nuclear would also be better but more difficult to begin for all the listed countries except South Africa since it requires extensive capital and scientific technology.

Also notable is the fact that only 40% of the electricity used at the mine was actually generated in Namibia. Creating more sustainable energy and electricity generation within Namibia would also create more jobs and cease the dependence on other countries, especially South Africa. Namibia already depends on South Africa for the majority of its products so creating some independence in electricity generation would be extremely beneficial to its economy. This would strengthen the already existing electricity industry and encourage scientific innovation in the field.

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APPENDIX A: NONPROLIFERATION, SAFEGUARDS AND SECURITY

A.1 Nuclear Nonproliferation

The Atomic Energy and Radiation Protection Act ensures that control exists in the production, processing, possession, sale, export, and import of nuclear material. It also protects people and the environment from radiation's possible harmful effects. Its Atomic Energy Board is the government's advisor on nuclear energy especially in terms of recommending regulatory standards and advising on obligations from the IAEA's Safeguards Agreement and Additional Protocol to the Safeguards Agreement. The Atomic Energy and Radiation Protection Act also created the National Radiation Protection Authority to specifically protect the health/safety of workers, the public and the environment. This Authority establishes radiation exposure extents, inspects practices and radiation sources/material, enforces regulations, and maintains the register of radioactive material [Nujoma, 1998]. The uranium mines in Namibia contain low grade uranium so uranium mining is not much different than general mining but the International Atomic Energy Agency (IAEA)'s guidelines still need to be followed [Swiegers, 2008].

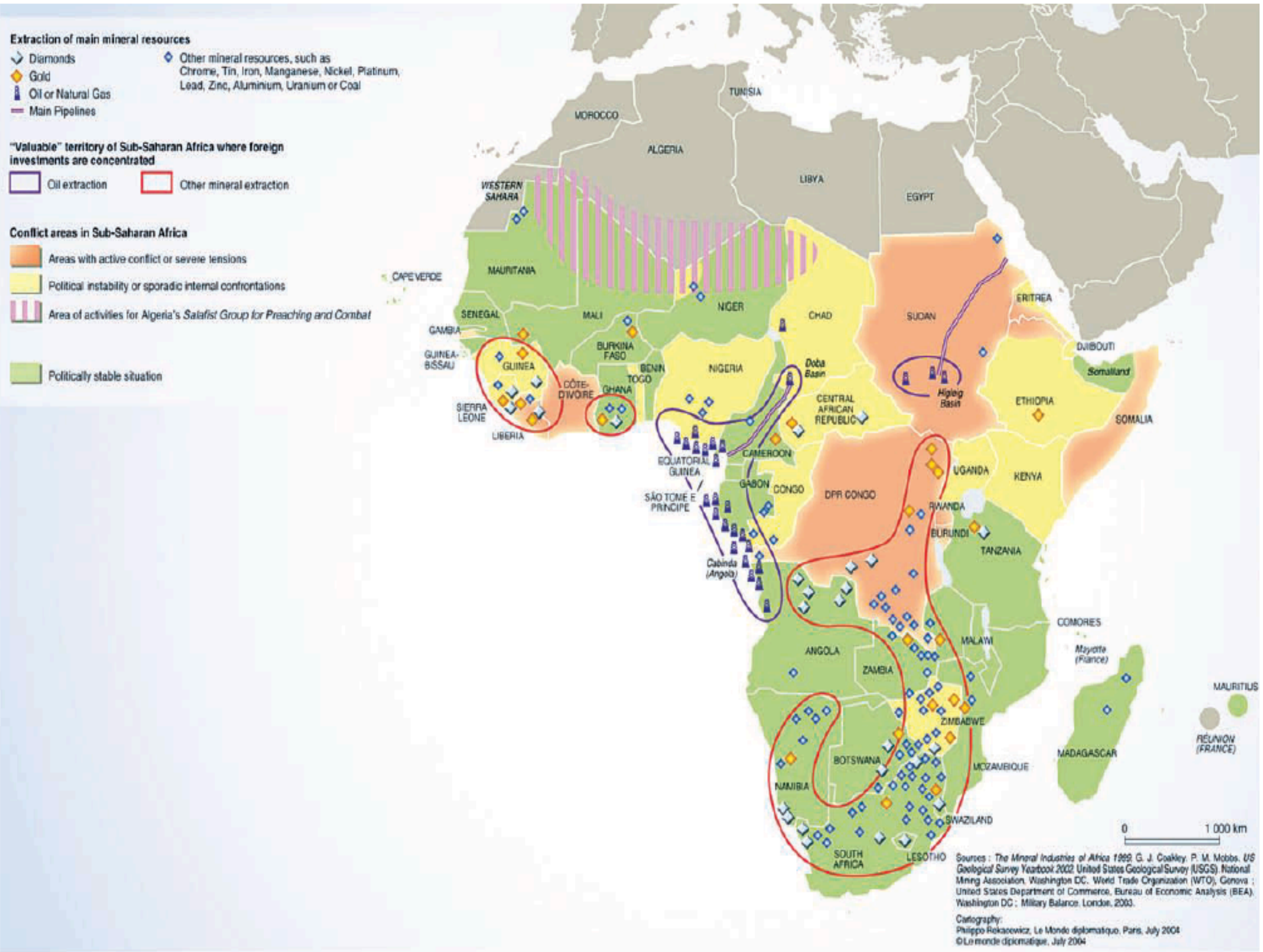
Namibia is party to the Nuclear Non-Proliferation Treaty and has had a comprehensive safeguards agreement in force since 1998. They also signed the Additional Protocol in 2000. The Atomic Energy Act of 2005 regulates uranium mining and there is an established Atomic Energy Board that works with a National Radiation Protection Authority [World Nuclear Association, 2013].

A.2 Safeguards Concerns in Namibia

In terms of proliferation concerns, Namibia is not likely to be a terrorist threat but it is possible that nuclear material will be stolen or 'lost'. According the Nuclear Materials Security index from the Nuclear Threat Initiative (NTI), Namibia is considered a "country without weapons-usable nuclear materials". It achieved a score of 49 overall. This is a combination of 71 for Societal Factors, 53 for Domestic Commitments and Capacity, 33 for Global Norms. Based on these scores, it can be seen that Global Norms requires the most improvement followed by Domestic Commitments and Capacity then Societal Factors. Global Norms includes international legal commitments, voluntary commitments, and nuclear security and materials transparency. Domestic Commitments and Capacity includes UN Security Council Resolution (UNSCR) 1540 implementation, domestic nuclear materials security legislation, safeguards adoption and compliance, and an independent regulatory agency. Political stability, pervasiveness of corruption, and group(s) interested in illicitly acquiring materials is considered in Societal Factors [Nuclear Threat Initiative, 2012]. Figure A.1 shows various examples of resource related conflicts in sub-Saharan Africa.

The below, Figure A.1, shows the stability of Namibia in comparison to the rest of Sub-Saharan Africa. Although Namibia ranks low in the global Corruption Perception Index (61st out of 180 countries), 49% of Namibian respondents for the Afrobarometer feel that government officials are corrupt. There seems to be a gradual corruption of the new elite, SWAPO (South West Africa People's Organization), whom won independence from South Africa in 1990 [Kohrs, 2012].

In 1997, the Chemical Weapons Convention (CWC) was created to curb the increase of chemical weapons. According to the IAEA in 2010, Namibia is one of the states that had not adopted legislation covering all key areas of Article VII Obligations. It also had not yet taken administrative measures to control transfers of scheduled important chemicals. It was also a state that "had no national program for protection against chemical weapons, or had not provided information to the Technical Secretariat (TS) on their national programs" [US Department of State, 2010]. This, combined with the NTI's rating, makes Namibia's uranium mining industry less secure than desirable.



Sources : *The Mineral Industries of Africa 1999*, G. J. Coakley, P. M. Mobbs, *US Geological Survey Yearbook 2002*, United States Geological Survey (USGS), National Mining Association, Washington DC; World Trade Organization (WTO), Geneva ; United States Department of Commerce, Bureau of Economic Analysis (BEA), Washington DC ; Military Balance, London, 2003.

Cartography:
Philippe Rekacewicz, Le Monde diplomatique, Paris, July 2004
©Le monde diplomatique, July 2004

Figure A.1 Mineral Resource Related Conflicts in Sub-Saharan Africa.[3]

Legislation in Namibia also lacks safeguards in regards to exporting uranium. The MME was granted permission by the government to pursue plans for a nuclear power generation plant so uranium may be used locally in the future rather than being exported. This means a nuclear regulatory framework will be needed [Shindondola-Mote, 2008]. The government has claimed a plan to supply its own electricity from nuclear power by 2018 but there is no evident progress [World Nuclear Association, 2013]. They are also working on a nuclear fuel cycle policy document.

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[3] This figure was previously published in [Southern Africa Resource Watch, 2008]. Permission is included in Appendix E.

Finland's Radiation and Nuclear Safety Authority (STUK) is partnering with Namibian officials to develop uranium mining policies as well as a safeguards and non-proliferation regime [World Nuclear Association, 2013].

A.3 Conflicts Resulting from Mining

In addition to terrorism and proliferation concerns, mining causes additional issues in developing countries due to poverty and violence. For instance, in Mali, Niger and Algeria, the Tuareg and governments have clashes over areas rich in resources such as uranium and gold or even land and water. Often African politics are difficult, especially in times where national sovereignty breaks down due to a rebel army [Abdalla, 2009]. Although this is unlikely in Namibia as the government is quite stable, many countries nearby are having conflicts including Angola, Zimbabwe, the DRC, etc. When the state loses power, multinational corporations (MNCs), foreign nations, rebel groups, and governments must compete over to gain control over profits by any means possible such that they often inflict harm on the population and the environment of the areas with the resources they seek [Abdalla, 2009].

Due to this, Namibia's uranium mining industry needs to be very secure so nearby rebel groups do not get control of radioactive waste or uranium. A sustainable livelihoods framework (SLF) can be used to visualize opportunities and assets available as well as their vulnerability sources. It can be used for both times of peace and conflict [Abdalla, 2009]. A Simplified version of an SLF is shown in Figure A.2.

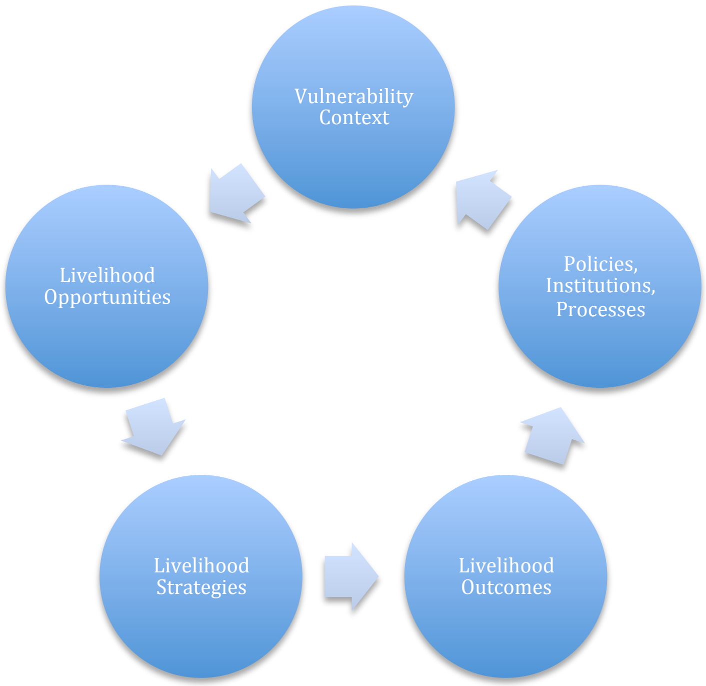


Figure A.2 Simplified Version of a Sustainable Livelihoods Framework.

In the figure above, vulnerability context must include financial, human, natural, physical, social, and political aspects. The policies, institutions and processes can be anything from government and laws to foreign investment and conflicts/violence. As natural resources diminish, conflicts are more likely to occur between different groups as well as the government. Since uranium should reach its peak production around the year 2015 [Dittmar, 2011], this could be a major concern for Namibia's security. Environmental change is also a major concern. In Namibia, desertification, deforestation, soil erosion and lack of water are constant challenges that can increase conflict. In addition, extreme weather including droughts and floods is increasing such that many livelihoods can be affected including farming, herding, fishing, etc. [Abdalla, 2009]. Many Namibians depend on weather-affected occupations for their food and money.

In African countries, it is very common for foreign companies to make profit while the country suffers and remains poor. For instance, Niger is one of the poorest in the world despite having some of the world's largest uranium deposits. Niger has barely benefited from the 100,000 tons of uranium extracted over the past forty years. Niger, like Namibia, has help in uranium mining from France's AREVA. Other countries have also begun exploring for uranium in Niger including China Nuclear International Uranium Corporation (SinoU), Rio Tinto, and India Taurian Resources Pvt Ltd. [Abdalla, 2009] The Tuareg in Niger were so frustrated with the mining industries taking their land that they formed the Movement for Justice (MNJ). The MNJ is "fighting for greater economic development and a fair share of northern Niger's uranium wealth" [Abdalla, 2009]. It demands 50% of the share for local authorities and believes uranium exploration by the government of Niger and foreign companies will lead to an imminent ecological disaster. The UN declared on 14 September 2007 that people cannot be removed from their land without their free and informed acceptance [Abdalla, 2009].

In Mali, uranium and gold reserves were a major factor leading up to the Tuareg conflict with the government. Grazing lands and water had been used by mining industries such that desertification had increased. The lack of lucid environmental policies and development priorities, in addition to population growth, land degradation and erratic rainfall causes the population to be in extreme competition for the scare remaining resources [Abdalla, 2009]. These causes of conflict could certainly occur in Namibia if the mining industry is not careful of its impact.

A macro level analysis implies that uranium mining increases the risk of intrastate conflict by 10% in comparison to the control or baseline [Koos, 2012]. There is an even larger likelihood of conflict due to ethnic exclusion, which also happens often in resource rich areas of Africa. A micro level analysis shows that uranium instigated conflicts are spatiotemporally feasible in Namibia, as well as the DRC, Niger, and South Africa. Although only Niger has had a extensive uranium related conflict so far, it is possible to be a concern for Namibia, South Africa, and the DRC in the future [Koos, 2012]. Much of this conflict stems from four main aspects of uranium mining:

1. Uranium is an efficient, effective source of energy
2. Uranium can be used in nuclear weapons so it is wanted by superpowers, terrorists, and

other groups

3. Revenue from uranium production is attractive for political powers, especially in Africa
4. Its production leads to human hazards as well as major ecological damage

In addition, a lack in regulations and understanding of mining issues often leads local communities off much worse than before. Overall, the assumption can be made that uranium operations increase the risk of violent conflict. Also, due to previous group conflicts, it can be assumed that if uranium mining is taking place in the homelands of marginalized groups who are excluded from the benefits but have to bear the burdens, such as land disputes and pollution, conflict is more likely [Koos, 2012].

In general, resource rich areas are more likely to have conflict. Resources can contribute to rebellion through three main mechanisms:

1. Motives to rebel including competition over resource revenues
2. Opportunity by making rebellion and warfare financially/militarily feasible due to looting
3. Indirect mechanisms such as socioeconomic development, encouraged rent-seeking behavior, land disputes, etc. [Koos, 2012].

Looking at these mechanisms for uranium mining in Namibia specifically, motives exist including struggle against mining firms and the central government. There are grievances about radiation and other effects on human health as well as the environment. Conflicts over scare land and water resources can also be an issue in Namibia. In terms of opportunity, uranium is hard to loot due to large industrial operations and investments needed. Yet, as a part of the fuel cycle, uranium mines remain a significant financial and military gain; facilities could be attacked, transport could be diverted, or workers could even be used for their nuclear knowledge. The possible indirect mechanisms are mainly the weakness of a relatively new governmental regime that is unsure how to regulate and implement safety, economic and environmental regulations, especially for the uranium mining industry, which has many components.

Another concern is the various ethnicities in Namibia. Although tribal conflicts since independence in Namibia have been peaceful overall, there remains a tension between differing races and tribes. Three major mechanisms are found to instigate ethnic conflicts:

1. Ethnic groups contain socio-psychological dynamics that can be used by individuals for financial or political aims
2. Ethnic groups can suffer from real or perceived relative deprivation or inequalities
3. Ethnically diverse societies tend to grow more slowly and have limited public good provision

[Koos, 2012].

Namibia contains a portion of the relatively well-known native tribe known as the San (Bushmen) who have been disputing land with the government of Namibia as well as South Africa and Botswana. Issues including mineral claims, hunting rights, political representation, basic services, land access/ownership and resettlement have become an immense concern [Jasparro, 2009].

Overall, the combination of Namibia's diverse ethnicity, economic distribution inequalities and resource rich areas makes uranium mining a security concern. Some mining areas are near the homelands of a small ethnic group that is categorized as deprived: the Topnaar Nama. They live near the Rossing mine and experience environmental degradation as well as economic deprivation, and limited political impact.

Additionally, local Namibians mainly work in low-level positions in the industry. Even more concerning is the fact that the Iranian government holds 15% of the Rossing mine [Kohrs, 2012]. "In 2011 the Namibian government initiated negotiations with Iran regarding holding in trust the Iranian 15% share in Rossing while UN sanctions on Iran apply, or Epangelo buying that share" [World Nuclear Association, 2013]. It is likely that its many resources were part of Namibia's motivation to fight for its independence from South Africa. From colonization until independence, Namibian resources were exploited by foreign entities [Kohrs, 2012]. Even now, the majority of the mining companies are based in foreign nations.

On the other hand, Namibia is part of many multi-state organizations, which strengthen its infrastructure. Much of its infrastructure was built while owned by South Africa such that the sparsely populated country is still well connected. In addition, resources were not crucial to the armed fight for independence though they may have played a role [Koos, 2012].

Namibia's neighbor, South Africa, could serve as a guide for uranium mining regulations and practices. Although in past South Africa was not a good role model, it seems to be gradually improving the worker safety and environmental impact of uranium mining. In the past there were high concentrations of radioactive substances found near Johannesburg (2008). Currently, concerns exist about acid mine drainage, destruction of aquifers, and dust pollution. But, fortunately, these conflicts are expressed through nonviolent marches and protests. Some ethnic groups that are marginalized exist in both South Africa and Namibia including the Xhosa and Zulu. Additionally, it has been reported that the Namaqualand region was chosen as a nuclear waste disposal site due to its distance from white settlements [Koos, 2012].

Security concerns can stem from environmental factors related to the vulnerability in combination with the resilience of natural and human systems [Jasparro, 2009]. Southern Africa, including Namibia, has had a significant increase in environmental awareness as well as political and economic development. Yet the political and economic will to remediate current environmental issues remains insufficient [Jasparro, 2009].

A.4 Conflicts in Namibia

The uranium mining conflict can be simplified into two main phases. The first began with Rossing, which began operating in 1976. Many of these struggles related to the fight for independence. It also coincided with the anti-nuclear movements of many other countries including the UK, Germany, Japan, etc. This was especially important because Namibian uranium was being exported to the UK and Namibia was part of South Africa. This international campaign highlighted the appalling wages, living conditions, and worker rights in Arandis, which is the town build by Rossing for its workers. This led to worker strikes but the uprising was quickly shut down due to the apartheid regime's prohibition on unionizing [Kohrs, 2012].

The second phase consisted of a reaction to the so called 'uranium rush' that is currently present in Namibia. This rush has occurred due to the increased demand of uranium along with the increase in price. This led to more exploration in Namibia such that 66 exclusive licenses were granted and at least three mines were to open soon. Earthlife Namibia and the Labor Resources and Research Institute (LaRRI) began a campaign about consequence of a 'uranium rush'. They also documented health conditions and had conferences with foreign experts. The Topnaar community publicly announced their concerns with the exploitation of the Aussinanis Reptile Uranium deposit near/in their territory. In addition, many tourist organizations proclaimed their concerns along with the communities in and around Swakopmund. There was even a legal battle questioning the Ministry of Agriculture Water and Forestry's decision to grant water abstraction permits to another Namibian mining company, Valencia Uranium [Kohrs, 2012].

There has been a halt in nuclear activities due to the Fukushima disaster since prices fell. Nonetheless, several Namibian projects are still moving forward even though Earthlife Namibia restarted its antinuclear campaign [Kohrs, 2012].

A.5 Inequitable Distribution of Wealth

Namibia has an extremely high wealth disparity index according to the World Bank. This could be a concern because it means wealth is divided very unequally and therefore the mining industry is controlled by a limited number of individuals. Due to globalization, it has been argued that the difference in prosperity and welfare within and between countries has increased. The development process of a country inherently forces some groups to be included and others to be excluded [Abdalla, 2009]. This makes laws and agreements essential such that peace can be maintained as development continues.

Persistent inequality in access to land and natural resources can lead to major conflicts especially in impoverished areas. Since mining and climate change increase desertification, Namibia is continually losing valuable land resources. This affects many economic pursuits including farming, raising livestock, fishing and tourism. Before colonization, Namibia mainly consisted of shared land that was occasionally fought over between tribes. Competition between farmers and herders has always existed but there was enough land for both until outside countries colonized and began to extract minerals including uranium and gold [Abdalla, 2009]. Namibia is classified as an Upper Middle Income Country but half of the population lives below the international poverty line of US$1.50 per day [Rena, 2012].

A.6 Conclusion

Although Namibia's recent independence makes it ripe for conflict, it has learned well from the experiences of other mining countries and is careful to mitigate issues when they occur. It has copied many laws from South Africa and Western countries so the only issue is the implementation. Some mines are on important land, either traditional villages or natural reserves, so care must be taken to avoid conflict. Overall, a good job has been done but there remains a chance of conflict, especially with the threats of more droughts from climate change. More people will fight as mines and other infrastructure replace grazing and faming land. Namibia must be aware of likely conflicts on the horizon, especially considering the countries extensively inequitable distribution of wealth.

APPENDIX B: RELATED LEGISLATION ON MINING, ENVIRONMENT AND NUCLEAR ENERGY

B.1 International Conventions and Protocols

International Conventions and Protocols on uranium mining are numerous. The most important are:

- The SADC Protocol on Mining - 1997
- The Atomic Energy and Radiation Protection Act – accepted by Namibia in 2005
- The Radiation Protection Convention - 1960
- The Occupational Cancer Convention - 1974
- The Working Environment (air pollution, noise and vibration convention) – 1977
- The Occupational Safety and Health Convention -1981
- The Occupational Health Services Convention - 1985

B.2 Namibian Legislation and Policy

The second sparsest in terms of population (after Mongolia), Namibia has relaxed health concerns as well as limited resistance to nuclear infrastructure [Puigmal, 2011]. Water is scarce; this usually minimizes groundwater contamination because there is extensive natural filtering before runoff reenters the groundwater supply. The limited population means that land is quite cheap. There is also limited corruption and consistent GDP growth. The policy-making bodies related to uranium mining include the Ministry of Environment and Tourism (MET), the Ministry of Mines and Energy (MME), the Ministry of Water Affairs (MWA) and the Chamber of Mines (COM). The constitution of Namibia declares the government's promise to maintain "ecosystems, essential ecological processes and biological diversity of Namibia" and utilize "living natural resources on a sustainable basis for the benefit of all Namibians both present and future" in Article 95

[Shindondola-Mote, 2008]. The government had attempted to institute a 5% royalty on non-diamond mining companies in 2004 but they then deemed it to be determined in a case-by-case basis because the companies complained extensively. In 2000, the non-diamond corporate tax was replaced by a flat rate of 37.5%, which is comparable to African countries but lower than developed uranium mining countries like Australia and Canada [Kohrs, 2012].

To obtain mining license there are certain procedures that must be followed:

1. Get exploration approved by the mining commissioner
2. Find sufficient deposits for mining
3. Obtain an environmental clearance certificate from the MME
4. Obtain an approved environmental assessment
5. The MME and MET will visit the exploration sites
6. Apply for a mining license and pay a fee of N$2000
    1. Be clear about mining location
    2. Get a cartography done in the mapping office
    3. Turn it in and obtain recipient
    4. Wait for mediation
    5. The commissioner will summarize its content then submit it to the Ministers
7. It will be rejected if does not meet Act requirements
8. Mining experts visit mining sites

In terms of governance for this industry, The COM issued the Labor Act - Health and Safety Regulations in 1992, The Atomic Energy and Radiation Protection Act in 2005, and The Environmental Management Act in 2007. The Labor Act is currently being updated but has not been finished [Kohrs, 2012].

The Atomic Energy and Radiation Act No 5 of 2005 is currently only at the draft stage in Namibia. There are currently too many loopholes [Kohrs, 2012]. The Environmental Management

Act focuses on analyzing the environmental effects of infrastructure including uranium mining [Kohrs, 2012]. It makes it mandatory for companies to produce an EIA for any listed activities. The Environmental Management Act includes the establishment of Sustainable Development Advisory Council within a new Environmental Commission office [Shindondola-Mote, 2008]. Thus Council works to create organization and cooperation between the government, NGOs, community based organizations (CBOs), the private sectors and funding agencies. The EMA also presents a framework for impact assessment laws with a set of environmental management principles and environmental protection measures [Louw, 2012].

The New Environmental Act of 2007 lacks a plan for closing mines and does not require and EIA. In addition, there is a Nature Conservation Ordinance (No. 4 of 1975) was actually broken when exclusive prospecting licenses (EPLs) were given for the Namib Naukluft National Park, which includes the Langer Heinrich mine [Kohrs, 2012].

In 2003, the government created a minerals policy to "ensure the sustainable contribution of minerals to the socioeconomic development of Namibia". The MME makes and enforces this and related policies [Mobbs, 2004]. There is a basic mining law, the Minerals (Prospecting and Mining) Act, from 1992. It is currently under review as it lacks important regulatory concerns such as a mine closure plan with rehabilitation. It also only states that the MME may require an EIA [Kohrs, 2012]. It prohibits prospecting or mining without acquiring the needed licenses and working within the regulations. There is even a section, 130, devoted to ensuring that those with licenses prevent the pollution of the environment [Louw, 2012]. Additional important legislation includes:

- *Water Act* 54 of 1956; *Water Resources Management Act* 24 of 2004.
- *Atmospheric Pollution Prevention Ordinance* 45 of 1965.
- *Town Planning Ordinance* 18 of 1954
- *Township and Division of Land Ordinance* 11 of 1963
- *Nature Conservation Ordinance* 4 of 1975

- *Nature Conservation Amendment Act* 5 of 1996
- Relevant town planning scheme(s).
- *Atomic Energy and Radiation Protection Act* 5 of 2005
- *Hazardous Substances Ordinance* 14 of 1974
- *Labor Act* 6 of 1992.
- *Nature Conservation Ordinance* 4 of 1975
- *Nature Conservation Amendment Act* 5 of 1996
- *Soil Conservation Act* 76 of 1969; *Biosafety Act* 7 of 2006.
- *Communal Land Act* 10 of 2002
- *Traditional Authorities Act* 7 of 1995
- *Nature Conservation Ordinance* 4 of 1975
- *Nature Conservation Amendment Act* 5 of 1996
- *Regional Councils Act* 22 of 1992
- *Regional Councils Amendment Act* 5 of 1996 [Louw, 2012].

B.3 Analysis

Although it appears than Namibia has sufficient laws, it is actually such that there are too many different laws and policies so that the regulatory structure is fragmented and divided between various committees, sectors, ministries, etc. Enforcing many of these policies is also not possible due to limited employees with sufficient mining and engineering expertise. The Environmental policies must come from 2-3 government ministries, which makes efficient, effective policies very difficult to determine, write, implement and enforce.

Legally, the Minister of Mines and Energy has the power to grant or deny a mining license. An Environmental Assessment is not required, only a summary of the current environmental situation of the proposed site, an estimation of the impact mining would have, and methods for mitigating any adverse effects. Nevertheless, it appears to be common practice to require an

Environmental Assessment to accompany any application. If the mining is planned to occur in a protected area, additional written permission from the Minister of Mines and Energy is needed. If the proposed site is in a game reserve or nature reserve, the Directorate of Parks and Wildlife Management must also provide written permission. No consultation or meeting of any kind is required with the surrounding communities or other stakeholders [Carpenter, 2009]. The MME and MET have inadequate coordination when determining whether or not to grant a license.

The Minerals (Prospecting and Mining Rights) Committee (MPMRC) and the Mining Commission together make the final decision after reviewing an application for a mining license. The MPMRC is composed of eight technical staff from the MME with representatives from the Ministry of Environment and Tourism as well as the Ministry of Finance [Carpenter, 2009].

It appears that environmental management is, for the most part, left entirely at the discretion of the mining company. Although there is a Uranium Stewardship Committee in the Chamber of Mines, it is "voluntary, not legally binding, not independently monitored and there are no penalties for non-compliance" [Kohrs, 2012]. The Uranium Stewardship Structures include Technical Advisor Committees (TAC) and the Health, Environment and Radiation Safety Committee (HERS). The Uranium Stewardship TAC Committee that is most important to this study is the Strategic Environmental Assessment one [Swiegers, 2009]. The Ministry of Environment and Tourism also has a policy on environmental assessment. These assessments must be undertaken by any and all mining projects. Yet there is no legislation to mandate this practice. There is a policy on mining and prospecting in protected areas stating that it requires an additional document when prospecting is in a protected area. It also states that an EIA must be conducted along with an Environmental Management Plan (EMP) [Shindondola-Mote, 2008].

B.4 Conclusion

Overall, there seems to be a relaxed atmosphere of regulation, perhaps to encourage international mining ventures. The government must ensure that they balance the current mining industry with the need for future ecotourism and biodiversity concerns. Foreign direct Investment (FDI) must also be balanced with rewards for the workers and the overall Namibian standard of living [Boocock, 2002]. Namibia has quite a few laws and regulations relating to mining but there needs to be much more work to enforce and strengthen these laws. The MME is drafting a law specifically for uranium mining with specifications related to the IAEA's guidelines. It will develop clear regulations for the industry [Shindondola-Mote, 2008].

Unfortunately, nuclear industry knowledge is very minimal and is basically zero for the majority of the population, even many workers. This means that their democratic rights are not very useful in terms of nuclear and uranium mining policies. Earthlife Namibia is attempting to increase public knowledge but there is a lot more that must be done [Shindondola-Mote, 2008].

APPENDIX C: PREVIOUS MINING LIFE CYCLE ANALYSES

Table C.1 Previous Uranium and Mine Studies

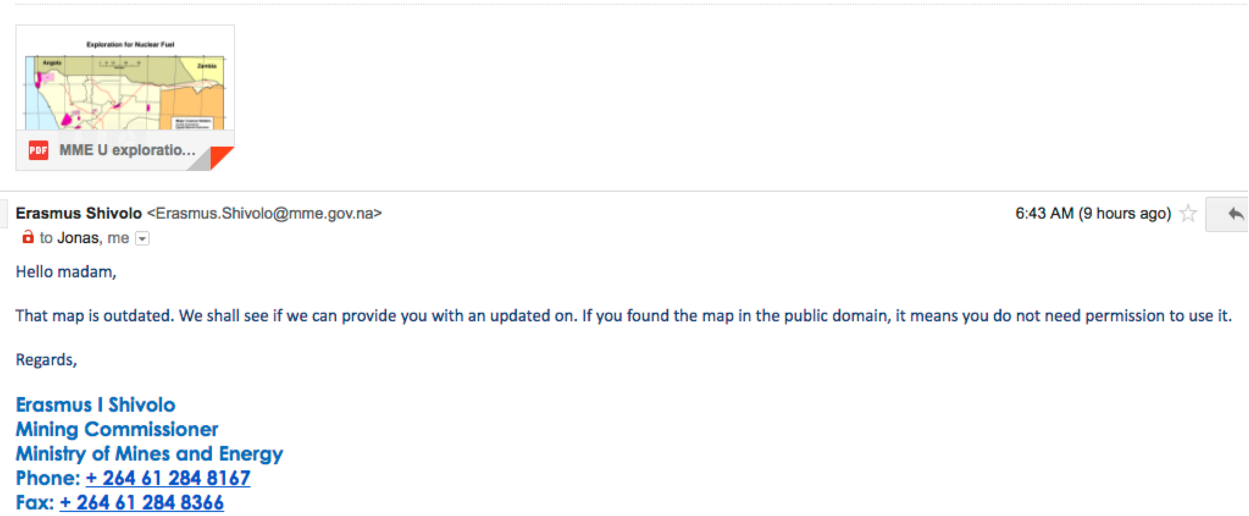
Source	Location	Investigator	Study Type
Foster, 2010	Austrailia Ranger U mine	university scientists	energy inputs and CO2 emissions of nuclear
Lenzen, 2008	Australian U mines	university scientists	LCA of energy balanace and GHG emissions
Dones, 2003	French and Swiss BWRs	scientist for Swiss Centre for LCIs	Greenhouse gas emissions and LCA from elec sources
Fritsche, 2006	German electricity systems	Ecology Institute	LCA of nuclear power and renewables
Kaminietz, 2011	German nuclear plants	university scientists	carbon leakage
Akabzaa, 2011	Ghana	independent	EIA discussion
Akabzaa, 2012	Ghana	independent	environ/health impact
Doka, 2009	global/general U mines	Doka Life Cycle	general LCI
Krause, 2010	Husad in Swakop	Metago Environmental Engineers	air quality impact assessment
Irish, 2009	Langer Heinrich	Gobabeb	invertebrates
Henschel, 2009	LHU	Gobabeb	vertebrates
Theron, 2009	LHU expansion	landscape architects for environ engineers	specialist study
Mudd, 2006	Malawi mine	Engineers	comments on EIA
Kunakemakorn, 2011	McArthur River Mine (Canada)	Thai scientists/engineers	LCA of nuclear power of European Power Reactor
Durucan, 2006	mines	engineers	new LCA specific for mining
Adey, 2011	mining in general	European Comission	carbon footprint
MacGregor, 2000	Namibia	MET and Dept of water affairs	value of water
Wotan, 2009	Namibian U mines	scientist	water/power usage
Tandlich, 2012	Namibian U mines	scientist	bioremediation
Dalal-Clayton, 2012	Namibian U mines	for MME	Strategic Environmental Assessment (SEA)
Kohrs, 2012	Namibian U mines	scientist	future power demand
Stephens, 2001	Namibian U mines	medical person	health
Louw, 2012	Namibian U mines	Nam grad student	LCA
Mudd, 2008	Ranger Mine (Australia)	scientist	embodied energy estimate
Kohrs, 2012	Rossing	indepe org = CRIIRAD	soil, sediment, water, rad
Kohrs, 2013	Rossing	medical person	health
Mudd, 2006	Rossing	Rossing	worker health
Wassenaar, 2012	Rossing	African Wilderness Restoration	biodiversity
Liebenberg, 2012	Rossing (Z20)	Airshed Planning Professionals (consulting)	air quality
Aurecon, 2012	Rossing (Z20)	Aurecon and SLR Environ consulting	Social/Environ management plan
Wiewiorra, 2010	Sweden	Vattenfall	LCAs on electricity sources
Cunningham, 2006	Trekkopje	scientist for mining co	EIA
Mannheimer, 2006	Trekkopje	for mining co	EIA focused on vegetation
Burke, 2009	Trekkopje	for Areva	biodiversity biotope assessment
Van Eeden, 2009	Trekkopje	IDA World Congress	EIA of desalination plant
Fthenakis, 2007	US and European reactors	BNL and Columbia scientists	Greenhouse gas emissions for nuclear and solar
Mudd, 2000	US U mines	Australian PhD student	pollution from In Situ Acid leaching
National Renewable Energy Lab, 2013	USA	National Renewable Energy Laboratory	LCA comparison for nuclear and other elec
Meier, 2002	USA	university scientists	LCA comparison for nuclear and other elec
Schneider, 2010	USA	Idaho National Laboratory	Environmental footprint
Liebenberg-Enslin, 2008	Valencia U mine	Airshed Planning Professionals (consulting)	air quality impact assessment
Mudd, 2007	various U mines	scientist	water/power usage, C02 emissions
Nilsson, 2008	various U, C, Cu mines	thesis students of Sweden	environ/health impact
Kilick, 2009	Walvis Bay sulfur plant	Aurecon and SLR Environ consulting	Social/Environ impact assessment
Dones, 2005	Western European reactors		Ecoinvent LCI for nuclear and natural gas systems
Weisser, 2007	World lit review	IAEA	greenhouse gas emissions from elec sources
WNA, 2011	World lit review	World Nuclear Association	LCA comparison for nuclear and other elec
Lenzen, 2008	World lit review	Centre for Integrated Sustainability	LC energy and Greenhouse gases of nuclear
Ashton, 2001	Zambezi, Limpopo Rivers	scientists	water resources and quality

APPENDIX D: LIST OF ACRONYMS

AMD	Airspace Maritime Defense (South Africa)
CMN	Chamber of Mines Namibia
CWC	Chemical Weapons Convention
EIA	Environmental Impact Assessment
EITI	Industries Transparency Initiative
EMP	Environmental Management Plan
EPL	Exclusive Prospecting License
GDE	Groundwater-dependent Ecosystems
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HAW	High Active Waste
HERS	Health, Environment and Radiation Safety Committee
IAEA	International Atomic Energy Agency
ICMM	International Council on Mining and Metals
ICRP	International Commission on Radiological Protection
ISL	In Situ Leaching
LAW	Low Active Waste
LCA	Life Cycle Analysis
MAW	Medium Active Waste
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MET	Ministry of Mines and Tourism
MME	Ministry of Mines and Energy (Namibia)
MNJ	Movement for Justice (in Niger)
MOX	Mixed Oxide Fuel (Plutonium and natural/slightly enriched Uranium)
NSGRP	National Strategy for Growth and Reduction of Poverty
NTI	Nuclear Threat Initiative
SADC	Southern African Development Community
SEA	Strategic Environmental Assessment
SLF	Sustainable Livelihoods Framework
TAC	Technical Advisor Committees
WNA	World Nuclear Association
WHO	World Health Organization

APPENDIX E: FIGURE PERMISSIONS

E.1 Figure 2.2 Permissions



Erasmus Shivolo <Erasmus.Shivolo@mme.gov.na>

Hello madam,

That map is outdated. We shall see if we can provide you with an updated on. If you found the map in the public domain, it means you do not need permission to use it.

Regards,

Erasmus I Shivolo
Mining Commissioner
Ministry of Mines and Energy
Phone: + 264 61 284 8167
Fax: + 264 61 284 8366

Figure 3 is from 2008/2009 and many of the names (license holders) no longer exist.

E.2 Figure 2.3 Permissions

Dear Janine,

Yes, you can use that map. Could you please quote this map as part of my publication in Global Environmental Change (see details below)
Conde and Kallis, 2012
http://www.sciencedirect.com/science/article/pii/S0959378012000313

Please note though that this map is not updated and corresponds to the period I was analysing (2010-12). Since Fukushima and the drop of uranium price the situation has changed a lot, but I am sure you already know this!

Marta

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The author would like to note this figure appeared in: Puigmal, Marta Conde and Kallis, Giorgos. The Global Uranium Rush and its Africa Frontier Lessons from Namibia. Global Environmental Change (2012) 596-610.

E.3 Figure A.1 Permissions

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Best,

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Janine N. Lambert graduated from the University of Michigan with a Bachelor of Science degree in Nuclear Engineering and Radiological Sciences. During her undergraduate years, she spent her free time with the Michigan Community Scholars program, in which she became a resident advisor, along with other extracurricular activities that focused on volunteerism such as Relay for Life and service trips to New York, Arizona, Louisiana, and throughout Michigan. She also interned with Brookhaven National Laboratory in the Energy Sciences Department and worked with various University of Michigan engineering departments. She also tutored with America Reads in Detroit and organized events to encourage science study such as pre-college engineering programs.

She then moved to Florida for her Master's study of Environmental Engineering. After taking classes, she interned with Brookhaven National Lab's Nonproliferation and National Security Department. She then departed for Peace Corps Namibia as a Master's International student of the University of South Florida. In Peace Corps, she taught math and science at a small village in the Caprivi/Zambezi region of Namibia for two years and then worked for an educational NGO, Star for Life Namibia, for a year for her extension of service. Peace Corps changed her life, challenged her worldview and will forever be a part of her existence. When returning stateside, she obtained an internship in Global Security and International Safeguards at Idaho National Lab where she now works.