Challenges of Nuclear Waste Management accompanying the Nuclear Renaissance in Developing Countries. With a Case Study of Zambia

A Master's Thesis submitted for the degree of “Master of Science”

supervised by
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Vienna, 17.06.2020
Affidavit

I, ARMITA HAGHI, B.A., hereby declare

1. that I am the sole author of the present Master’s Thesis, "CHALLENGES OF NUCLEAR WASTE MANAGEMENT ACCOMPANYING THE NUCLEAR RENAISSANCE IN DEVELOPING COUNTRIES. WITH A CASE STUDY OF ZAMBIA", 62 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted the topic of this Master’s Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 17.06.2020

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Signature
Abstract

Developing countries with growing populations and economies are experiencing an increasing demand in energy. Consequently, numerous developing countries are considering nuclear energy. Vendors from countries with long-term experience in nuclear power hereby offer financing. Several countries in Africa are experiencing a nuclear renaissance and are starting to explore options to increase the share in nuclear power, yet none of the plants emerging from such contractual arrangements with vendors have been commissioned so far. With a lack of experience, resources and labor force, it is important to examine if developing countries are ready for nuclear power programs and if they have the capacities to run the plant for its entire lifetime. This includes the management of radioactive waste, which is an issue that accompanies a nuclear power plant far beyond its productive lifetime and therefore affects many future generations. The aspect of radioactive waste management in relation to such contracts will be the focus of this paper.
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AFRA</td>
<td>African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology</td>
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<tr>
<td>BWR</td>
<td>Boiling water reactor</td>
</tr>
<tr>
<td>HLW</td>
<td>High level waste</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
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<tr>
<td>IGA</td>
<td>Intergovernmental Agreement</td>
</tr>
<tr>
<td>ILW</td>
<td>Intermediate level waste</td>
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<tr>
<td>LLW</td>
<td>Low level waste</td>
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<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
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<td>NEPIO</td>
<td>Nuclear energy program implementing organization</td>
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<tr>
<td>NPP</td>
<td>Nuclear power plant</td>
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<tr>
<td>NRWMC</td>
<td>National Radioactive Waste Management Centre</td>
</tr>
<tr>
<td>PWR</td>
<td>Pressurized water reactor</td>
</tr>
<tr>
<td>RR</td>
<td>Research reactor</td>
</tr>
<tr>
<td>SNF</td>
<td>Spent nuclear fuel</td>
</tr>
<tr>
<td>VLLW</td>
<td>Very low-level waste</td>
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<tr>
<td>VSLW</td>
<td>Very short-lived waste</td>
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</tbody>
</table>
Acknowledgements

I wish to express my deepest gratitude to my supervisor, Dr. Kaluba Chitumbo for taking time to discuss my topic, his guidance and help throughout the process of writing my thesis. I would like to pay my special regards to Dr. Reuben Katebe, who was willing to participate in an interview and who patiently answered my questions. Furthermore, I would like to recognize the invaluable support that my family provided throughout my studies. Finally, I wish to thank Prof. Winiwarter, who has first brought this topic to my attention during her course “Environmental History”.
1. Introduction

This thesis focuses on the question if developing countries considering nuclear power meet the requirements to handle the waste generated from the nuclear power plants. This issue will be analyzed first with the help of the methodology, which is elaborated in chapter 2, and a subsequent case study in chapter 3.

Chapter 2 will start with the status of nuclear power in Africa, summarizing all emerging projects that are planned on the continent. The subsequent step will be a definition of requirements that need to be met in order to implement nuclear power. Section 2.3 of the second chapter focuses on radioactive waste management, first providing general information such as a classification of radioactive waste, legal framework, storage and disposal possibilities, waste generated from decommissioning, concluding with a description of goals and purposes and strategic approaches of radioactive waste management.

Chapter 3 comprises a case study for which Zambia was chosen as one of the numerous countries in Africa that are considering nuclear power. The case study will include contextual information on Zambia as a country, followed by information on the planned nuclear research reactor and power plant. Then, parameters will be listed which define the scope of the case study. Based on the findings elaborated in the methodology in chapter 2, criteria for the management of spent nuclear fuel will be identified. Each criterion will be elaborated in a separate section and examined in relation to Zambia. It will be assessed whether Zambia meets the requirements for managing radioactive waste generated from a nuclear power plant. For each criterion either an assessment or a recommendation will be provided. An interview with Dr. Reuben Katebe, National Coordinator for the Nuclear program in Zambia, will complement the third chapter. Serving as a means to answer additional questions that could not be covered by the available material, the interview provides further insight into the project development from the point of view of an expert in the given field. Subsequent to the interview a qualitative assessment will be presented. The case study can be utilized as a blueprint that is applicable to other developing countries in a similar situation.
2. Methodology

The methodology includes primarily material from IAEA Safety Standard series, as well as further publications from the IAEA and the OECD’s NEA, which deal with the management of radioactive waste. Further information on the emerging projects in Africa and specifically in Zambia was provided by Rosatom and Rusatom Overseas. The following section will introduce the challenges Africa is facing in relation to the numerous nuclear power programs which are planned for the future. Nuclear waste is one of the difficulties that need to be overcome in relation to these emerging projects. The case study will examine if Zambia meets the requirements to handle nuclear waste and where further research and development of resources might be necessary.

2.1. Status of nuclear power in Africa

With economies on the rise, developing countries, especially in Africa, require reliable sources of energy. Climate change being a global issue, the need for non-CO2 emitting energy options leads many countries towards nuclear power. With two operational reactors, South Africa is currently the only country on the African continent with nuclear power (IAEA 2019a, 10). More precisely, South Africa has two nuclear power plants at the Koeberg nuclear power station and a research reactor. Nuclear power generates 5% of the country’s electricity, while the rest is mainly generated by coal (International Energy Agency 2019). The National Radioactive Waste Disposal Institute (NRWDI) takes on the task of radioactive waste management. For low- and intermediate level waste from Koeberg a repository exists at Vaalputs, while spent fuel is stored at the Koeberg power station itself (World Nuclear Association 2020a). Other African countries are following this example and have planned projects to build research reactors as well as nuclear power plants. The following table depicts the status of these emerging projects. It is important to understand this as the case study in this paper focuses on Zambia but shall be applicable to countries that are in a similar situation.

The World Nuclear Association lists the following African countries amongst those who are planning to start nuclear power programs: Egypt, Tunisia, Libya, Algeria, Morocco, Sudan, Nigeria, Ghana, Senegal, Kenya, Uganda, Tanzania, Zambia, Namibia, Rwanda and Ethiopia (World Nuclear Association 2020). Financing, public acceptance, and the availability of adequate infrastructure are essential factors in the implementation of such
projects (Gil 2018). Nuclear power plants are long term projects and must be accepted by the current government and public as well as the future ones. The waste generated by these power plants will affect future generations. As a number of nuclear power programs in developing countries are being financed by foreign vendors, it must be examined if these projects are beneficial for the countries in which the projects are being implemented. Table 1 focuses on projects from Rosatom, Russia’s State Atomic Energy Corporation, who are known to be financing most of the emerging projects in Africa as well as the project in Zambia. The Chinese National Nuclear Corporation (CNNC) is investing in overseas projects as well. While the CNNC has already made investments in Ghana, no further information on their projects in Africa has been provided so far (CNNC 2018).

Table 1: Potential nuclear facilities in Africa

<table>
<thead>
<tr>
<th>Location</th>
<th>Projects</th>
<th>Role of Rosatom</th>
<th>Agreement with Russia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt, “El Dabaa” Site</td>
<td>Planned by Rosatom: 4 light water reactors with 1200 MW each (Ofek 2017)</td>
<td>Providing nuclear fuel, assistance in labor force development, running the plant for the first 10 years (Rosatom 2020a)</td>
<td>MOU between the Russian Federal Service for Environmental, Technological and Nuclear Supervision and the Egyptian regulatory body for nuclear and radiological safety (Rosatom 2015)</td>
</tr>
<tr>
<td>South Africa, “Koeberg” NPP</td>
<td>Already existing NPP</td>
<td>Providing enriched uranium products (Rosatom 2020)</td>
<td>2014: IGA “on strategic partnership and cooperation in the sphere of nuclear energy and industry” (Rosatom 2020)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2015: 2 MOU (concerning public awareness and training of personnel) between Rosatom and South Africa’s Department of Energy (Rosatom 2020)</td>
</tr>
<tr>
<td>Location</td>
<td>Projects</td>
<td>Role of Rosatom</td>
<td>Agreement with Russia</td>
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</tbody>
</table>
| Nigeria  | Uranium exploration and mining (Rosatom 2020), construction of a power reactor (by 2025) and research reactor | Financing by Russia is confirmed, including the development of infrastructure, framework, and system of regulation for nuclear and radiation safety | 2009: cooperation concerning uranium exploration and mining  
2012: IGA between Rosatom and NAEC for cooperation concerning NPP construction  
2016: “cooperation in construction of a Center for Nuclear Research and Technology in Nigeria” (Rosatom 2020) |
| Ghana    | Assisting in the establishment of a nuclear industry | 2012: cooperation agreement between Rosatom and Ministry of Energy & Petroleum  
2015: nuclear cooperation agreement with Russia |
| Kenya    | Not specified | Assisting in the establishment of a nuclear infrastructure for the construction of a RR and NPP | 2016: MOU for peaceful use of nuclear energy between Rosatom and the Kenyan Council for nuclear energy (Rosatom 2020) |
| Tanzania | Mkuku River project: Uranium mining by Uranium One (owned by Rosatom) | preparatory work for ISL | MOU for the peaceful use of nuclear energy between Rosatom and the Tanzanian Atomic Energy Commission (TAEC) (Rosatom 2020) |
| Namibia  | Uranium One is conducting research on rare earth metals with Em- pangelo Mining Company |  | 2017: IGA on the peaceful use of nuclear energy (Rosatom 2020) |
| Uganda   | Not specified by Rosatom | Not specified by Rosatom | 2017: MOU on the peaceful use of nuclear energy (Rosatom 2020) |
2.2. Conditions for a nuclear power program

Before implementing a nuclear power program, several external factors must be taken into account. In numerous cases, especially in developing countries, the lack of finances, adequate infrastructure, and untrained labor force pose a problem in the implementation of such a program and create a situation in which the country is dependent on foreign help. The purpose of a nuclear power program is to ensure that these requirements are met before the construction of the nuclear power plant: “a nuclear power programme establishes the infrastructure necessary to support it during its entire life cycle, including planning, siting, construction, commissioning, operation, decommissioning, and spent fuel and waste management” (IAEA 2009c, 1). In the IAEA’s “Milestone Approach”, three phases (with a milestone at the end of each) are described towards the implementation of a nuclear power program.

![Figure 1: IAEA Milestone Approach (IAEA 2015, 5)](image)

The “Nuclear energy program implementing organization” or “NEPIO” concentrates on the realization of Milestones 1 and 2 (IAEA 2009c, 1).

Minimum requirements for the implementation of a nuclear power program include:
- A legal framework encompassing the nuclear power program (e.g. national policy)
- Regulatory authorities overseeing safety and environmental issues
- Financing
- Material resources (planning and construction of premises for power plant and waste storage facilities)
- Labor force
- Procedures guaranteeing safe operation of the power plant
- Public outreach and approval

(IAEA 2006, 1)
2.3. Radioactive waste management

Radioactive waste is a product of nuclear power generation, as well as the use of radioactive materials in research, medicine, education, and industry. In some countries, radioactive waste is also generated in support of defence activities (IAEA 2018, 5). In this paper, the focus is on the radioactive waste generated from nuclear power for civil use. Different types of radioactive waste are the by-product of nuclear power generation, and every part of the nuclear fuel cycle contributes to the waste generation (IAEA 2018, 10). Each country that has nuclear activities must also manage the waste generated from these activities in an adequate manner. The IAEA specifies certain guidelines on managing radioactive waste, which are available to its Member States (IAEA 2009b). In the IAEA Safety Glossary, radioactive waste is described as material for which no further use is foreseen that contains, or is contaminated with, radionuclides at activity concentrations greater than clearance levels as established by the regulatory body (IAEA 2019, 186). Radioactive waste management is defined as all administrative and operational activities involved in handling, pretreatment, conditioning, transport, storage and disposal of radioactive waste (IAEA 2019, 187). Conditioning refers to the preparation of the radioactive waste for further management, more precisely for handling, transport, storage and/or disposal (IAEA 2019, 187). The following figure indicates which pathways and approaches may be taken in the management of radioactive waste.

![Figure 2: Pathways for management of radioactive waste (IAEA 2019, 187)](image-url)
2.3.1. Classification of radioactive waste

Waste emerging from radioactive materials is likely to have adverse effects on human beings and their environment. To facilitate handling, it is classified by type. Each type of radioactive waste has a regulation that is applied to it, depending on the level of radiation and the risk accompanied by it (IAEA 1996, 1).

The IAEA differentiates between the following types of waste:

- **Exempt waste**: not under “regulatory control for radiation protection purposes” (IAEA 2018, 6)
- **Very short-lived waste (VSLW)**: after a few years of required storage this type of waste can be cleared from regulatory control
- **Very low-level waste (VLLW)**: requires a high level of containment and isolation, can be disposed of in near-surface facilities. Regulatory control is limited
- **Low-level waste (LLW)**: is “above clearance levels” (IAEA 2018, 6), which means that it is not exempted unlike the levels of waste listed above. It differs from higher levels of waste by containing a limited number of long-lived radionuclides and must be isolated accordingly for several hundred years. Low level waste can be disposed of in near-surface facilities.
- **Intermediate-level waste (ILW)**: contains a higher number of radionuclides, and thus requires more secure isolation than low-level waste.
- **High-level waste (HLW)**: heat that is produced due to radioactive decay is the decisive factor that differentiates high level waste from other types of waste. HLW contains a high number of long-lived radionuclides. All of these factors must be taken into account in the engineering of high-level radioactive waste disposal facilities, which should be located a few hundred meters below the surface. (IAEA 2018, 6)
2.3.2. High-level waste and spent nuclear fuel

Spent fuel is defined as “nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form because of depletion of fissile material, poison buildup or radiation damage” (IAEA 2019, 223). Spent nuclear fuel is generated in the reactor and transported directly after its use from the reactor to a pool to be stored for three to five years. The method of disposal for spent fuel and HLW depends not only on the characteristics of the waste but also whether an open or a closed fuel cycle is chosen. In the open fuel cycle spent fuel is not reprocessed, ending as high-level waste, while in the closed fuel cycle the spent fuel is reprocessed by recovering the uranium and plutonium (IAEA 2009b, 28) eventually ending up in a geological repository for final disposal.

The most common approach chosen is interim storage of the spent fuel, which allows constant supervision and extraction in case reprocessing or disposal might be (re)considered (IAEA 1999, 3).

2.3.3. Storage of HLW and SNF

Storage is defined by the IAEA as: “[holding] the waste during its processing (buffer storage), to hold unconditioned waste until it reaches clearance levels (decay storage), to temporarily hold waste prior to its transport to a disposal facility or to hold waste until a final waste repository becomes available” (IAEA 2009b, 22). After its lifetime in the reactor, spent fuel (uranium rods which are used for producing nuclear fuel) is transferred from the reactor to an on-site storage pool underwater due to high temperatures and
radiation, where it then remains in for several years in for cooling and radiation shielding until it can be further transported to a storage or disposal facility (IAEA 2009b, 28). Storage facilities can be located “at the reactor (AR)” or “away from the reactor (AFR)”. AFR storage facilities can be either located at the reactor site (RS), containing a supplementary interim storage facility where the waste can be stored 50 to 100 years. This category can either contain an extra pool, in which the spent fuel is stored, or a dry storage facility with the possibility to be moved from the site. AFR storage can also be “off the reactor site (OR)”. 92% of AFR storage is wet storage and only 8% is dry (IAEA 1999a, 1-2).

To conclude, after its three to five years of cooling, the following three options exist:

1. Intermediate storage
2. final disposal
3. reprocessing

Which option is chosen depends on several factors, which will be further examined in section 2.3.6. Due to limited “reprocessing and disposal capacities” (IAEA 2019b, 2), a high level of uncertainty hovers above the question of how to manage spent fuel after storage, making an extension of storage periods necessary (IAEA 2019b, 2). This so-called “wait and see approach” (IAEA 2013, 33) is a solution for many countries. Spent fuel storage periods are often extended because final solutions, such as disposal and reprocessing, require political, legal and public acceptance and might not be implemented in the foreseeable future (IAEA 2019b, 2). Furthermore, reprocessing is not encouraged due to proliferation concerns, and very few countries have the capability to reprocess due
to the demanding technological and financial implications. The fact that storage of spent fuel is being extended beyond its initial duration must be accepted, and optimization of this kind of storage is necessary in order to meet safety requirements.

Past assumptions of available capacity for spent fuel reprocessing and disposal have often been wrong, resulting in missed opportunities to implement policies and strategies. For example, dry cask storage systems (DCSSs) were originally conceived to free up space in reactor spent fuel pools and to provide spent fuel storage of up to 20 years until sufficient reprocessing or deep geological disposal capacity became available. Hundreds of DCSSs are now employed throughout the world and will be relied upon for well beyond their originally envisioned design life. (. . .) The risks and uncertainties associated with extending spent fuel storage can never be completely eliminated. They can however, be managed to ensure that the likelihood of an unanticipated occurrence is sufficiently low that its consequences are sufficiently mitigated to render the risk acceptably low (IAEA 2019b, 3-4).

Amount of waste generated from reprocessing

2% of SNF is fissile material that can be reprocessed. This fissionable material contains 1% 235U and 1% plutonium and minority actinides. Additional waste streams linked to this process are a result of the different steps of procedure, with long-lived ILW being the principal waste stream deriving from reprocessing (IAEA 2013, 11).

1 ton of reprocessed PWR fuel results in (after conditioning):

- HLW: 0.1 m³
- ILW: 0.5 m³
- LLW: 1.5–2 m³
- Uranium: 950 kg (handled as long-lived waste) (IAEA 2013, 11)

2.3.4. Disposal of HLW and SNF

After the spent fuel or HLW has spent a certain number of years in “interim storage” (IAEA 2018, 21), it is prepared for disposal. This includes a reduction of volume (containment) as well as isolation so that it can be stored in a deep geological repository (IAEA 2018, 21) (IAEA 2003, 3). While storage is a temporary solution, disposal is a long-term solution, which makes use of a “passive system made up of engineered and natural barriers” (IAEA 2003, 3) without the possibility of extracting the material at a later point in time, as it is possible during storage.
Containment and isolation of the waste is provided both by the containers into which the waste is put before being emplaced in the repository and by various additional engineered barriers and the natural barrier provided by the host rock (...) the most commonly studied rock types being clay, salt, and hard magmatic, metamorphic or volcanic rocks such as granite, gneiss, basalt or tuff. The depth at which the disposed material would be emplaced depends to a large extent on the type of formation used and the isolation capacity of the overlying formations. Suitable clay formations, for example, tend to occur in layers of a few hundred metres thickness at a depth of a few hundred metres. Salt deposits occur as bedded salt layers or salt domes at this or greater depths. For disposal in hard rocks, the usual design depth is between 500 and 1000 m, and the aim is to use parts of the rock formation that contain very few large fracture zones or faults (IAEA 2003, 3).

Several countries with nuclear power plants are considering the option of deep geological disposal and doing research on how to implement it, for example, France, Sweden or Finland (IRSN 2013, 18, 20). A disposal facility will be constructed near the island Olkiluoto in Finland, by the company Posiva Oy, which specializes in the final disposal of radioactive waste. The site’s construction license was granted in 2015. Posiva will apply for the operating license in 2020 (Posiva Oy n.d.). Sweden is also planning on building a repository for spent nuclear fuel in Formarsk. A request to construct the repository has been filed in 2011 by the Swedish company SKB (SKB n.d.). Storage cannot provide an “ultimate solution” (IAEA 2012a, 2) to the management of SNF. Disposal possibilities should be taken under consideration, as additional fuel will be produced, and resources of SNF storage will be depleted. The option of disposal will be considered in the case study following in section 3, although the main focus will be on storage, as disposal has not been implemented in any country so far and requires resources that many developing countries might not have developed so far.

2.3.5. Decommissioning

Decommissioning is defined as “the process of defueling, deconstruction, and dismantling of a nuclear power plant” (Focus Europe 2019, 34). This process can take up to 20 years and generates a high amount of radioactive waste (Focus Europe 2019, 17). Therefore, a strategy for handling the waste that is involved in this process must be incorporated in the actual waste management strategy from the beginning. Such a plan should be usually developed by the vendor before commissioning. Decommissioning generates different types of waste, with the largest fraction of it being VLLW and LLW, which can be handled in the same manner as operational waste. Material from within the reactor can contain long-lived radionuclides and is classified as ILW. In certain cases, even HLW can be generated from decommissioning (OECD 2006, 69). The volume of decommissioning waste resulting from a 1000 MW PWR or BWR is approximately 5,000- 10,000
m³ (IAEA 2013, 9-10, 15-16). Certain materials such as concrete, steel, and other metals and used equipment can be recycled from the decommissioned site. The process of decommissioning and the waste generated throughout the process can differ from site to site, depending on the numbers of sequences that must be completed in order to decommission the site - therefore, a reference site is chosen for each case (OECD 2006, 63-64, 69). Usually, the polluter pays principle applies to costs related to decommissioning. If this cannot be applied, the government takes over the costs. Due to the fact that nuclear power programs are long-term projects, assessing the exact costs so far in advance poses a challenge. A lack of data availability, knowledge, and expertise are further causes for miscalculations, as full decommissioning and dismantling has so far only been successfully completed by the USA, Germany and Japan (Focus Europe 2019, 13). To conclude, not only do ongoing nuclear power plants generate waste, but also plants that are being decommissioned. Storage solutions are scarce, with Finland having reached 93% and Sweden 80% of their storage capacity. Therefore, radioactive waste is an issue that accompanies a nuclear power plant for a long period of time, even after its operational period (Focus Europe 2019, 43).
2.3.6. Guidelines and agreements

The IAEA provides a number of recommendations, guidelines, and agreements that assist Member States in implementing and planning the management of nuclear waste in a safe and correct manner. A brief overview is provided in the table below.

<table>
<thead>
<tr>
<th>Name</th>
<th>Goals and scope</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management</td>
<td>Achieve and maintain a high level of safety in SNF and radwaste management (IAEA 2013, 3)</td>
<td>Further guidance and implementation infrastructure necessary binding on Member States that have signed (IAEA 2013, 3)</td>
</tr>
<tr>
<td>Milestone approach</td>
<td>Infrastructure development for new nuclear power program with defined milestones (IAEA 2015, 2-3)</td>
<td>Waste management not treated in detail for each milestone (IAEA 2013, 4)</td>
</tr>
<tr>
<td>Integrated Nuclear Infrastructure Review (INIR) (IAEA 2013, 4)</td>
<td>Peer reviews assessing a country’s development of a nuclear power program external despite coordination by IAEA use of milestones approach (IAEA 2013, 4)</td>
<td>An international expert group performs the review upon request of a Member State (IAEA 2013, 4)</td>
</tr>
<tr>
<td>IAEA Safety Standards for the Processing, Handling, and Storage of Radioactive Waste</td>
<td>Establishes guidelines and recommendations for quality (IAEA 2008, 1-2)</td>
<td>The IAEA Safety Standards are not binding; the responsibility is carried by each member state by itself</td>
</tr>
<tr>
<td>NEPIO (Nuclear Energy Program Implementing Organization) (IAEA 2009c)</td>
<td>Deals with infrastructure development for a nuclear power program with a focus on phases 1 and 2 of the Milestone Approach</td>
<td>The infrastructure development also focuses on requirements for the entire lifecycle, such as “planning, siting, construction, commissioning, operation, decommissioning, and spent fuel and waste management” (IAEA 2009c, 1)</td>
</tr>
</tbody>
</table>
2.3.7. Considerations and strategies for radioactive waste management

Countries planning to implement a nuclear power program must make the following **considerations** associated to their waste management strategy:

- Responsibility for the waste
- Development of infrastructure
- Financing
- Human resource development
- Project management (planning milestones)
- Storage location and alternative options
- International cooperation

(IAEA 2013, 33)

In regards to the above-mentioned considerations, a project dealing with the management of radioactive waste should be initiated, starting with the following **assignments**:

- setting up a team of professionals in the field
- assigning tasks and responsibilities
- verifying on-time commissioning of necessary facilities for “collection, handling, treatment, and conditioning of operational waste and for storage of SNF” (IAEA 2013, 34)
- providing for required storage capacity
- analysis and development of potential disposal opportunities (IAEA 2013, 34)

**Establishment of a waste management strategy**

As each phase of the nuclear fuel cycle generates waste, a waste management strategy must be established before the construction of a nuclear power plant and the facility for the waste generated by the plant. The following section will define conditions that a country requires in order to handle the waste generated by a nuclear power plant, specifically spent nuclear fuel. An overview of existing guidelines for radioactive waste management will be presented, and as a further step, the findings will be combined and modified,
creating a model that will then be applied to a specific case. Before elaborating the conditions, the following points will be outlined:

- Necessity and importance of guidelines
- Responsibility of handling the radioactive waste
- Goals and objectives of radioactive waste management
- Achievement of goals and objectives

**Necessity and importance of guidelines**

The necessity of guidelines for the management of radioactive waste due to low standards and preparedness in developing countries is an issue that has been addressed in several publications so far. A number of developing countries with nuclear power programs face obstacles such as mismanagement of finances, shortcomings in human resources, the absence of a legal structure, and awareness for certain safety standards (IAEA 1995, 9).

There is a need for the establishment and implementation of a national waste management programme. Such a programme must include all of the elements of an integrated system, including laws and regulations, operating and regulating organizations, systems of processing/storage and disposal of waste and an effective public acceptance out-reach. No programme is complete nor will it succeed if one of these components is missing (IAEA 1995, 13).

A national policy should be connected to a technical strategy. The national policy develops a set of standards for radioactive waste management, while the technical strategy helps implement the policy (IAEA 2009b).
A further crucial step that must be taken before establishing a strategy for the management of nuclear waste is to define who is responsible for its management. The selected option may differ from state to state. Possible options are depicted in Table 3 (IAEA 2009b, 21).

Table 3: Options for waste management strategies (IAEA 2009b, 21)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Details and allocation of responsibilities</th>
<th>Comments (possible advantages &amp; disadvantages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National waste management strategy</td>
<td>One managing body develops a national plan</td>
<td>National policy must be adopted by the government, so each government that succeeds is obligated to accept it</td>
</tr>
<tr>
<td>A two-level strategy</td>
<td>The government develops a national strategy which is then further specified and carried out by the waste owners</td>
<td>The expertise of the waste owner is adopted by the government. Government involvement provides continuity to the policy. This method enhances the management of waste, strengthens safety and security and provides efficiency in the use of resources</td>
</tr>
<tr>
<td>one strategy for a particular type of waste</td>
<td>e.g.: one strategy for low-level waste, intermediate waste, HLW and spent fuel (long- or short term), respectively</td>
<td>You need to differentiate between a strategy and methodology. This is not compatible with a clear understanding of a strategy. It is a method; therefore, a strategic approach is required</td>
</tr>
<tr>
<td>no national strategy</td>
<td>Some countries choose not to establish a national strategy for radioactive waste management, so the responsibility is with the owner</td>
<td>If the owner goes bankrupt, the country is left without a strategy</td>
</tr>
<tr>
<td>waste generators hold responsibility</td>
<td>The waste generators choose whether a strategy is required</td>
<td>This option can also bare risks, as a strategy provides security</td>
</tr>
</tbody>
</table>

In addition to the distribution of responsibilities, the choice of the waste management strategy is linked to regional requirements such as the national legislative system, time limits and schedules, the selected technologies, the type of fuel cycle and to which extent the given country can rely on itself in terms of supply, services and labor force (IAEA 2013, 34).
Goals and objectives of radioactive waste management

- **Volume reduction**

- **Concentration of waste and containment of radionuclides with the aid of a “waste matrix and waste container followed by disposal in an appropriate disposal facility designed to provide isolation from the biosphere”** (IAEA 2009b, 22)

- “**[the protection of] individuals, society and the environment from the harmful effects of ionizing radiation due to spent fuel and radioactive waste, both now and in the future**” (IAEA 2009b, 22)

Additional considerations and factors influencing the chosen strategy

As there may be a variety of technologies to choose from, decisive factors in radioactive waste management are time management and using adequate means in order to reach the goal. Further prerequisites for the handling of radioactive waste, as listed in the previous section, shall be considered as well. In order to secure commissioning without a postponement, a well-structured plan and a precise identification of goals for each step are indispensable (IAEA 2009b, 31). A further factor impacting the strategy of radioactive waste management is the decision on where and how the waste ultimately will end up (IAEA 2009b, 32). The following table provides an overview of options for the final destination of radioactive waste.

Table 4: Options for final destination of radioactive waste (IAEA 2009b, 31-32)

<table>
<thead>
<tr>
<th>Option</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste recycling</td>
<td>Selected for materials with high metal content</td>
</tr>
<tr>
<td>Immediate disposal</td>
<td>Desired approach. Requires availability of disposal and predisposal facilities</td>
</tr>
<tr>
<td>Deferred disposal</td>
<td>Frequently used approach due to unavailable predisposal and disposal facilities, consideration of reprocessing or national tendency towards near-surface storage solutions</td>
</tr>
<tr>
<td>A multinational solution</td>
<td>in most cases, waste is stored nationally until a multinational solution is developed</td>
</tr>
</tbody>
</table>
Public acceptance may additionally influence the choice of waste management strategy. As it is connected to the provided degree of safety, it is important to choose adequate waste management in order to “prevent accidents, minimize exposure to radionuclides and ensure radiological safety for workers and the public” (IAEA 2017, 1). Informing and including the public is essential in the process of obtaining public approval (IAEA 2017, 72).

An effective public information programme will be a useful effort in addressing concerns among members of the public. To the extent appropriate, the public should be brought into the process of site and technology selection. Neglecting such measures can result in a negative impact on public perception, especially when there is organized opposition to the construction of nuclear facilities (IAEA 2017, 72).

Opting for long-term storage of radioactive waste may also be linked to public acceptance as other options such as deep geological disposal or multinational solutions might be disputed among the public (IAEA 2017, 54). For developing countries in which vendors finance the construction of a nuclear power plant, it is also crucial to consider how the waste management and decommissioning will be financed after the plant has been taken over as the electricity tariff might not cover the costs.
3. Case study: Zambia

The following case study focusing on Zambia addresses if the requirements to implement a nuclear waste management strategy are being met. After a brief introduction of the country, as well as parameters and criteria, will be defined for the case study, followed by an examination of the individual criteria. Finally, a recommendation will be made, based on the results of the case study.

Zambia, a country in the south of Africa, is at an early stage of initiating nuclear power and research. As will be seen in the following section, Zambia has already completed negotiations with Rosatom and has signed to build a research reactor and a nuclear power plant, both of which are going to be financed by Rosatom, Russia’s state atomic energy corporation. Furthermore, Zambia is landlocked, which makes the question of transportation of spent fuel interesting to discuss, while countries like Kenya and Tanzania are near the sea, making transportation of spent fuel and thus reprocessing simpler. As will be further explained in the section concerning Zambia’s energy mix, the country has a good projection in terms of energy requirements. In Zambia there is a lot of willingness to build a nuclear power plant, which could be an important factor in terms of public acceptance. In regard to the political situation, terrorism threats are low, as the political situation in Zambia is considered stable. The following table will provide an overview of information on the country, which might be useful in connection to the management of radioactive waste (Central Intelligence Agency 2020).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Observable Parameter</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td>17.4 million (July 2020 est.) (Central Intelligence Agency 2020)</td>
<td></td>
</tr>
<tr>
<td><strong>Chief of State/ head of government</strong></td>
<td>President Edgar Lungu (Central Intelligence Agency 2020)</td>
<td></td>
</tr>
<tr>
<td><strong>Government type</strong></td>
<td>Presidential republic (Central Intelligence Agency 2020)</td>
<td></td>
</tr>
<tr>
<td><strong>Income Group</strong></td>
<td>Lower middle income (The World Bank Group 2019)</td>
<td></td>
</tr>
<tr>
<td>Indicator</td>
<td>Observable Parameter</td>
<td>Comments</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Region</td>
<td>Sub-Saharan Africa (The World Bank Group 2019)</td>
<td></td>
</tr>
<tr>
<td>Neighboring countries</td>
<td>Angola, Botswana, the Democratic Republic of the Congo, Malawi, Mozambique, Namibia, Tanzania, Zimbabwe (Central Intelligence Agency 2020)</td>
<td>This could be relevant for considering reprocessing</td>
</tr>
<tr>
<td>Capital</td>
<td>Lusaka (Central Intelligence Agency 2020)</td>
<td></td>
</tr>
<tr>
<td>Currency Unit</td>
<td>New Zambian kwacha (The World Bank Group 2019)</td>
<td></td>
</tr>
<tr>
<td>GDP growth per year</td>
<td>1.8 for 2019 (The World Bank Group 2019)</td>
<td></td>
</tr>
<tr>
<td>Natural resources</td>
<td>copper, cobalt, zinc, lead, coal, emeralds, gold, silver, uranium, hydropower (Central Intelligence Agency 2020)</td>
<td></td>
</tr>
<tr>
<td>Water resources (Ministry of National Development Planning 2017, 78)</td>
<td>Zambia has generous water resources. renewable water resources per capita: 8,700 m3 (Ministry of National Development Planning 2017, 78)</td>
<td></td>
</tr>
</tbody>
</table>
Before defining parameters and criteria which shall be examined in the case study, it is important to indicate which type of nuclear facilities will be constructed in Zambia. The following table provides an overview of these activities.

**Table 6: Status of nuclear facilities in Zambia**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Research reactor (CNST)</th>
<th>Nuclear power plant (Nuclear Business Platform 2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned</td>
<td>agreement signed in 2018 Building phase: 3-6 years (RAOS JSC 2018)</td>
<td>“Universal access by 2030” (Nuclear Business Platform 2019)</td>
</tr>
<tr>
<td>Use</td>
<td>medicine, agriculture, neutron activation analysis, mineral analysis, Chip manufacturing (Lwizi 2019)</td>
<td>Electricity generation</td>
</tr>
<tr>
<td>Financing</td>
<td>Rosatom</td>
<td>Rosatom</td>
</tr>
<tr>
<td>Location</td>
<td>10 km distance from Lusaka (RAOS JSC 2018)</td>
<td>Not known yet</td>
</tr>
<tr>
<td>Capacity</td>
<td>10 MW (RAOS JSC 2018)</td>
<td>2400 MW</td>
</tr>
<tr>
<td>Facilities</td>
<td>“laboratory complex, multipurpose irradiation center, cyclotron-based nuclear medicine center” (RAOS JSC 2018)</td>
<td>Normally standard supporting facilities that apply to NPP</td>
</tr>
</tbody>
</table>

**Zambia Center for Nuclear Science and Technology (CNST)**

In 2018, Zambia signed an agreement with Rosatom to build a research reactor, the Zambia Center for Nuclear Science and Technology (CNST), which will be used to “promote the growth of national education and science through the training of highly qualified experts in various fields” (RAOS JSC 2018). The CNST will be built at a distance of 10 km from Lusaka and comprise a nuclear research facility with “a multipurpose research water-cooled reactor, a laboratory complex, multipurpose irradiation center as well as a cyclotron-based nuclear medicine center” (RAOS JSC 2018). “[The] research reactor will be used for medical purposes as currently medical isotopes are being imported from South Africa. Also, the reactor is supposed to boost agricultural export to Europe and the US” (Nuclear Business Platform 2019). The use in agriculture is important, as it allows export activities to countries that only allow “gamma irradiated agricultural products to
enter their markets” (Lwizi 2019). Further use of the research reactor will be made by “neutron activation analysis, mineral characterization of various ore and detection of undeclared minerals thereby increasing mineral taxation [as well as] the treatment of cancer patients and easy detection of leaking pipes using isotope techniques and production of chips for computers and cell phones” (Lwizi 2019).

Nuclear power plant

According to the Nuclear Business Platform, Zambia is initiating nuclear energy in two phases, setting the foundation by first building a research reactor (Nuclear Business Platform 2019). Zambia is highly dependent on hydropower. As a result of this dependency, the drought that had occurred in 2015-2016 had major impacts on the country’s energy availability and economy. Consequently, Zambia’s economic growth experienced a 40% decrease (Lwizi 2019). Zambia must meet the prerequisites for the implementation of a nuclear program by developing its human resources, especially nuclear scientists and engineers (Mupuchi 2019).

3.1. Parameters and criteria

Table 7: Parameters for the case study

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Spent nuclear fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of storage</td>
<td>- Short term</td>
</tr>
<tr>
<td></td>
<td>- Long term</td>
</tr>
<tr>
<td>Possibilities of SNF storage</td>
<td>- Centralized</td>
</tr>
<tr>
<td></td>
<td>- On-site</td>
</tr>
<tr>
<td></td>
<td>- Off reactor site (IAEA 2019b, 13)</td>
</tr>
<tr>
<td>Open fuel cycle</td>
<td>The main focus of this blueprint lies on the option of an open fuel cycle. A model will be developed for the management of SNF after it has been used in the reactor and spent 3-5 years cooling down on-site in a pool</td>
</tr>
<tr>
<td>Closed fuel cycle</td>
<td>This point will be considered, with an examination of financial possibilities, available transport routes</td>
</tr>
<tr>
<td>Disposal options</td>
<td>Will be considered as well with an examination of geological formation</td>
</tr>
</tbody>
</table>
Based on the findings of the previous sections, the following criteria have been chosen to be decisive for developing a blueprint for the management of radioactive waste:

- Legal and political criteria and international cooperation
- Technical criteria (Safety, Security and Safeguards, Infrastructure)
- Economic criteria

In this case study, the individual criteria will be elaborated. It will be examined if Zambia has the resources to meet them (if the information is given), and otherwise if no information is provided, it will be examined and listed what should be done in order in order to meet the given criteria.

3.1.1. Legal and political criteria and international cooperation

A country’s political stability is strongly connected to its ability to implement a nuclear power program and to manage the radioactive waste in a safe way. Nuclear power programs are long-term issues; therefore, the political situation of the country must be taken into consideration. Furthermore, a country can benefit from international cooperation, especially if it has no or little experience in the given field. For this section, a list of prerequisites for policy development in terms of radioactive waste management will be presented, followed by an elaboration of each point. Finally, a recommendation will be made, concluding Zambia’s requirements for the establishment of a waste management strategy.

Prerequisites for policy development

The prerequisites for policy development in radioactive waste management are:

- Political stability
- A national legal framework, policies, and strategies
- An institutional structure, dealing with radioactive waste management and spent fuel management
- International cooperation
- Knowledge on the situation in other countries
Political situation

Zambia is a presidential republic (Central Intelligence Agency 2020). Since 1991 the country has restored its multi-party system, followed by eight elections, which had not been accompanied by any further difficulties. It is considered “one of the most stable countries in Africa [with a government that encourages] transparency, accountability [and] citizen participation” (Ministry of National Development Planning 2017, 33).

A national legal framework, policies and strategies

A national legal framework makes it possible to implement new policies concerning radioactive waste management and spent fuel management (IAEA 2009b, 10). As stated in Art. 19 of the Joint Convention, a legislative and regulatory framework is a prerequisite for managing radioactive waste and SNF (IAEA 1997). The given structure will ensure the development of safety requirements, licensing obligations for the operation of SNF and radioactive waste management facilities, control and inspection, and distribution of responsibilities. A policy for SNF and radioactive waste management is developed by the government and comprises essential targets and conditions guaranteeing safety and effective performance. In order to meet the objectives defined by the policy, a waste management strategy must be developed. The waste owner or the government can elaborate the waste management strategy. Different possibilities of allocation of responsibilities in a waste management strategy have been mentioned in section 2.3.7. In the case of Zambia, the project is financed by a vendor. Consequently, a two-level strategy would be suitable, where the government and the waste owners (i.e., the vendors, for the time they are running the plant) cooperate in the development of a national strategy. Generally, the government’s approval is required before all of the factors mentioned above can be considered. If the government does not provide the necessary capacities, a strategy for the management of radioactive waste cannot be developed (IAEA 1995, 22).

An institutional structure

An institutional structure should be established in the first steps of the implementation of a nuclear power program. This structure should take all the parts of the nuclear fuel cycle into consideration, including the management of radioactive waste. The “Nuclear energy programme implementing organization” or “NEPIO” concentrates on the realization of
Milestones 1 and 2 of the IAEA’s Milestone Approach and establishes the required structure for the construction and operation of a nuclear power plant (IAEA 2009c, 1). Phase 1 focuses on what must be taken into account before the initiation of a nuclear power program. After this phase a policy decision is made, followed by Phase 2 in which preliminary work for constructing a nuclear power plant is done (IAEA 2009c, 1). Each phase ends with a Milestone. In Phase 1, waste management is addressed concerning nuclear safety and funding and financing. Furthermore, the country’s ability to manage the radioactive waste will be examined, the waste volume will be estimated, and a strategy for handling it will be established. Additionally, the possibility of final disposal of HLW and SNF will be taken into account (IAEA 2009c, 6). In terms of waste management, Phase 2 concentrates on verifying legal and organizational aspects concerning LLW and ILW as well as establishing strategies for potential disposal opportunities for HLW and SNF.

International cooperation

International cooperation can offer an exchange of information, research and development, funding possibilities, guidance, and a set of rules and laws. Countries implementing a nuclear power program can benefit from international cooperation. As a member of the African Union (African Union Commission 2020), Zambia is also an active member of other agreements on the continent, two of which concern nuclear issues: the African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA) (IAEA, AFRA 2017a, 1) and the African Nuclear-Weapon-free zone treaty (The treaty of Pelindaba) (African Union 2017). Zambia signed on November 4th, 1996, and ratified on June 28th, 2010. Zambia is also a party to the IAEA’s “Treaty on Non-Proliferation of Nuclear Weapons” (IAEA n.d.). However, Zambia is not a party to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint convention). AFRA “is an intergovernmental Agreement established by African Member States to further strengthen and enlarge the contribution of nuclear science and technology to socio-economic development on the African continent” (IAEA, AFRA 2017a, 1). While not a party to the agreement, the IAEA provides assistance to the parties of the agreement regarding technical, scientific, financial, and administrative issues (IAEA, AFRA 2017a, 1). The AFRA Mandate connects the development of the member states infrastructure on a
regional level, with a focus on self-reliance in peaceful nuclear applications, which shall further support each country’s social and economic growth (IAEA, AFRA 2017a, 2). Its core functions are to assist countries in cooperation, development of human resources, infrastructure and research in the field of nuclear science and technology (IAEA, AFRA 2017a, 4). One of the main points of the agreement is the cooperation between its parties. Pursuant to Article I of the Agreement, its parties shall “promote and co-ordinate co-operative research, development and training projects in nuclear science and technology through their appropriate national institutions” (IAEA 2020a, 1). Article III of the agreement further specifies that the IAEA is authorized to assist when a party is drafting a proposal for a collaborative project (IAEA 2020a, 2). The Agreement further states in its Article VI that a national coordinator with extensive technical knowledge in the given field shall be responsible for projects within its territory (IAEA 2020a, 4). It is essential to bear in mind this point when the responsibilities for the project of a nuclear waste facility are allocated. Regarding projects with countries that are not parties to the AFRA Agreement, further details are specified in Article VIII, which states that the IAEA may invite non-Members to invest in projects or cooperate with Afra Member States with the approval of the Meeting of Representatives (IAEA 2020a, 5).

Knowledge on the situation in other (similar) countries: Ghana as example

Following the example of Ghana, which has a research reactor and a gamma irradiation facility, a regulatory body must be established in order to provide a legal basis. A legislative structure shall ensure nuclear and radiation safety (Glover und Fletcher 2000, 322-323), for which a “Radiation Protection Board” as well as a “National Radioactive Waste Management Centre (NRWMC)” are responsible in Ghana (Glover und Fletcher 2000, 321). The NRWMC is in charge of “a radioactive waste management infrastructure that will meet all the needs of Ghana” (Glover und Fletcher 2000, 321). The NRWMC program consists of two phases, with the first phase incorporating the development of administrative structures, regulations, and the “construction of radioactive waste processing and storage facility for the treatment, conditioning and storage of radioactive waste” (Glover und Fletcher 2000, 321). The second phase concentrates on the establishment and commissioning of a final disposal repository of radioactive waste (Glover und Fletcher 2000, 321). As Ghana is also a developing country on the African continent and
thus in a similar situation as Zambia, an exchange of information could be initiated, so that Zambia can gain more insight on Ghana’s nuclear power program.

To conclude, the waste strategy of Ghana incorporates all important factors, from handling the waste in the present to a more future-oriented approach with the establishment of a repository. At this point it is important to draw a comparison and remind the reader that this case study concentrates on SNF from a power reactor and the case of Ghana is for a research reactor. But the approach can be modified and taken over to fit the given case. Being a party to the AFRA agreement is definitely beneficial for Zambia, as it supports members in allocating responsibilities, and cooperation, while guidance is provided by the IAEA. Zambia is not a party of the Joint Convention (IAEA 2020). Still, it is recommended in the process of developing a nuclear waste management strategy to apply for accession, as the Joint Convention assists member states in achieving and maintaining a high level of safety in SNF and radioactive waste management.

3.1.2. Technical Criteria

The decision on how to store SNF and HLW depends on several factors. This section provides an overview of relevant considerations before choosing a method for managing SNF, followed by possibilities to store SNF as well as prerequisites for disposal.

Type of fuel cycle

As already elucidated in section 2.3, the type of fuel cycle chosen will influence the final mode of storage or disposal. The two options are either a closed (with reprocessing) or an open fuel cycle (without reprocessing). If Zambia were to consider reprocessing, the following factors must be taken into account:

- Transport route
- Financial resources
- Technical resources
- Will the vendor take back the fuel for reprocessing? Will this be part of the contract? If yes, will this be an option also after Zambia has been handed over the power plant?
All of these questions need to be clarified before selecting one of the two options. Zambia is landlocked with eight bordering countries, which means that a maritime transport route is not a direct option. Land transport is dangerous, and due to potential opposition, this option would involve negotiations with the countries that would be affected. In order to reprocess independently, financial and technical resources would be required. Reprocessing plants operate in very few countries, such as France, Japan, and Russia (IPFM 2020). A further option for reprocessing SNF would be “fuel leasing” (IAEA 2013, 30). In this option, the vendor takes back the fuel for reprocessing. In the case of Zambia, this would be realistic, as the vendor financing the project is from Russia, which has a reprocessing plant. However, it must be clarified beforehand if this option is ongoing for the lifetime of the plant or only as long as it is run by the vendors. For the customer country, this is a convenient option in terms of political and legal acceptance, as the responsibility for the waste is handed over to the lessee. The lessee, on the other hand, could profit financially from this option. Additionally, fuel leasing offers a better possibility to monitor fissile materials and is therefore beneficial in connection with safeguards (IAEA 2013, 30).

Time management/time periods for storage

Storage is not a long-term solution. However, many countries have extended storage periods while contemplating further options such as disposal or reprocessing. Therefore, storage periods are often extended. This fact must be taken into account in the engineering process for the storage facility. Per definition of SSG-15 (IAEA 2012a, 91), short term storage lasts up to 50 years and long term up to 100 years. Due to the absence of disposal facilities, an extension of storage over 100 years might be necessary (IAEA 2019b, 5).

Disposal

Deep geological disposal has not yet been implemented in any country so far, while it has been considered in some. As can be retrieved from section 2.3.4, Posiva Oy is going to apply in 2020 for an operation license for their disposal facility. Deep geological disposal is founded on the concept that radioactive waste is disposed of in the geosphere with multiple barriers providing safety. The hosting bedrock is supposed to provide stability over a long period of time and must, therefore, be thoroughly examined before
considering this form of disposal. “Repository concepts and potential host rocks differ between Member States. The main host rocks considered are igneous crystalline and volcanic rocks, argillaceous clay rocks and salts” (IAEA 2009a, 6).

Prerequisites:

- Stability and predictability of rock formations (IAEA 2009a, 6) (Posiva Oy n.d.)
- Water permeability of bedrock
- A multibarrier system: the individual barriers provide support to each other to a certain extent but must not rely completely on each other in case one barrier breaks down (Posiva Oy n.d.)
- technical barriers: SNF in ceramic state, iron or copper canisters, “bentonite buffer and the tunnel back-filling material [and] the bedrock function as a natural barrier” (Posiva Oy n.d.).

Whether or not such a technology can be implemented is highly dependent on the bedrock conditions. Regarding the case of Finland, the prerequisites are being met: The disposal facility will be located 400-450 inside the Olkiluoto bedrock (mainly magmatic gneiss, 1,800 to 1,900 million years old), the bedrock provides for stability and predictability at this depth. The disposal tunnels will not be built surrounding water conductive structures of the bedrock. The choice of the right location is important because the bedrock provides a natural barrier against contact of the disposal canisters with groundwater and further external influences. The conditions of the bedrock must be assessed in terms of chemical and mechanical stability and water conductivity, amongst others. The bedrock also provides radiation shielding. Disposal facilities are supposed to be placed more than 400 m deep, due to security reasons (it is difficult to reach them and retrieve material) and to safety reasons (preventing impact on the ground and atmosphere above the facility). “Deeper inside the bedrock, the stress conditions in the rock would make the construction of facilities more difficult. The salinity in the groundwater would also increase, which can have an adverse effect on the functioning of the bentonite” (Posiva Oy n.d.). The bedrock of the location for the disposal facility, Olkiluoto, has been observed and studied thoroughly for almost four decades. It must be considered that building such a facility and doing research is a costly measure that a developing country cannot bear without foreign investment. Whether Zambia meets the prerequisites for a disposal facility is out of the scope of this project and must be further examined in another.
Possibilities of SNF storage

- Centralized
- On-site
- Off reactor site

Spent fuel is stored on the reactor site in most cases. This bares multiple issues. After decommissioning the plant, the facilities are either preserved or the waste is relocated to a disposal facility or reprocessed. After decommissioning, the infrastructure is reduced to a bare minimum. Consequently, further investments must be made in order to maintain the spent fuel storage. Centralized storage and off reactor site storage options have the advantage that the issues related to decommissioning can be avoided. However, for off-site and centralized storage, a site must be selected, for which public and political acceptance is required. While it may be challenging to find a suitable location for a centralized storage facility, countries can profit in many ways from centralizing SNF storage: Initial investment costs can be high at first but can be shared between the sites for one centralized facility. It must be estimated beforehand if this is feasible for the parties involved. The same applies to infrastructure, licensing, and other requirements for a waste management facility. If a centralized facility is built, the burden of the organizational process is shared. A disadvantage of centralized storage facilities is the fact that higher volumes of waste could lead to more damage in case of an emergency, transportation costs, and risks (IAEA 2019b, 13). Zambia has a research reactor and a nuclear power plant planned, so a centralized facility could be an option. Furthermore, Rosatom is conducting uranium mining and ISL activities in two of Zambia’s neighboring countries, Tanzania and Namibia. For the case that Rosatom plans to invest in a nuclear power program in these countries, a multinational solution for the storage of radioactive waste of the three countries can be envisaged.
### Design criteria

#### Table 8: Design criteria for SNF storage

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Details &amp; goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Containment</td>
<td>multibarrier approach: ‘<em>fuel matrix, fuel cladding, the storage casks, the storage vaults and building structures</em>’ (IAEA 2012a, 29)</td>
</tr>
<tr>
<td></td>
<td>storage time extension can lead to material corrosion (IAEA 2019b, 4)</td>
</tr>
<tr>
<td>Subcriticality</td>
<td>Prevention of unplanned occurrences with incorporation of geometry planning in engineering process (IAEA 2019b, 4)</td>
</tr>
<tr>
<td>Decay heat removal</td>
<td>Prevents loss of geometry</td>
</tr>
<tr>
<td></td>
<td>Decay heat reduces over time. Low temperatures on the other hand, can pose a problem during transport as claddings can brittle (IAEA 2019b, 5)</td>
</tr>
<tr>
<td></td>
<td>energy produced by the spent fuel should serve as a power source (IAEA 2012a, 29)</td>
</tr>
<tr>
<td>Retrievability and transportability</td>
<td>Necessary for consideration of future options of SNF management (IAEA 2019b, 5)</td>
</tr>
<tr>
<td>Passive systems</td>
<td>minimum monitoring/human intervention</td>
</tr>
<tr>
<td></td>
<td>Important for cost reduction and safety (IAEA 2019b, 5)</td>
</tr>
</tbody>
</table>

In regard to safety systems, the following considerations should be taken into account:

- natural hazards (floods, earthquakes, volcanos) (IAEA 2019b, 10)
- incidence response should be possible by providing sufficient accessibility and retrieval
- additional waste streams should be avoided
- the storage system should be resilient to decay
- access must be provided for security controls
- The casks must be secure and withstand external influences (IAEA 2012a, 30, 33).

While incorporating the measures as mentioned above, especially developing countries must be cautious of the "overkill syndrome", which is characterized by the investment in technologies and materials that are far more advanced than required in the given case. Straightforward, efficient, and low-cost solutions should be preferred. Emphasis should be further made on research and development, not only technology transfer because the
country in which the nuclear power plant is built must be able to rely on itself after the plant is handed over by the provider (IAEA 1995, 24-25). The storage facility should be designed to meet the needs of the country and with regards to financial opportunities, whilst maintaining the highest level of efficiency. Taking appropriate measures in terms of siting and facility design and can also lower the risks and costs of SNF storage facilities (IAEA 2019b, 9). More precisely, designing facilities in such a way, that provides flexibility in terms of storage period extension and adjustment to different safety measures. Investments in proper design features may be costly at the beginning but are feasible during the life cycle of the facility (IAEA 2019b, 10).

Safety, Security, and Safeguards

Safety

Nuclear safety is defined by the IAEA as “the achievement of proper operating conditions, prevention of accidents and mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation risks” (IAEA 2019, 155). The facility may not operate before it has been verified by the regulatory body that the safety measures have been implemented. This includes each component of the system that could cause radiation risks (IAEA 2016, 8-9). The responsibility for safety lies with the “responsible legal person”, meaning “the person or organization responsible for the facility or activity” (IAEA 2016, 9).

Safeguards

Safeguards deals with military use of fissile material. A safeguards agreement is defined as an agreement of a Member State with the IAEA, that prohibits the military use of fissile material. Such agreements can be made on a bilateral or multilateral basis or concerning a project initiated by the IAEA (IAEA 2019, 205). In order to provide safeguards, the compliance with the following points must be guaranteed:

- Inspections confirming storage of nuclear material
- Incorporating safeguards features into the design by complying with national regulations
- Verifying the inaccessibility of unauthorized parties to nuclear material (IAEA 2019b, 11).
Security

Nuclear security is defined as:

the prevention and detection of, and response to, criminal or intentional unauthorized acts involving nuclear material, other radioactive material, associated facilities or associated activities \[and\] the prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive material or their associated facilities (IAEA 2019, 155).

Safeguards, safety, and security criteria may be interlinked. Many safety criteria that mitigate or prevent the effects of natural occurrences can also provide assurance in terms of safeguards and security. However, measures targeting specifically safeguards and security must still be incorporated into the design of the facility. These include supplementary barriers and monitoring systems (IAEA 2019b, 11-12). In order to ensure that all of the above-mentioned measures are incorporated in the design of the facility, it is recommended to comply with IAEA standards and to benefit from guidance that may be provided by the IAEA. In a statement at the 63rd regular session of the IAEA General Conference in Vienna, Austria, the government of the Republic of Zambia guaranteed to invest in developing human resources in nuclear safety, security, and safeguards. The statement also includes an acknowledgment of the necessity to adopt legal instruments under IAEA auspices in order to make use of nuclear science and technology for peaceful purposes. In regard to the statement, Zambia has identified key international legal instruments, which need to be ratified or sent to ratification in the year 2020. Additionally, Zambia has proceeded with the implementation of a nuclear bill, which shall “ensure effective protection from harmful effects of ionising radiation \[and\] the development of the nuclear programme in Zambia which meets the highest standards in public safety, security and safeguards” (Msiska 2019, 3-4). As Zambia’s nuclear power plant is being built by Rosatom, safety, security, and safeguards are provided by the vendor.
Siting and infrastructure Criteria

For this section, it is relevant to first touch upon siting and infrastructure development of nuclear power plants. Siting activities and the establishment of adequate infrastructure are strongly connected during the planning phase of a nuclear power program (IAEA 2012, 6). An environmental impact assessment is done before building a nuclear power plant in order to evaluate if the power plant itself or any of the facilities related to it (for example, a waste storage or disposal facility) will have an impact on the environment. The IAEA provides guidance for such an assessment while acknowledging that every country may handle it on their own terms. The figure below shows the infrastructure development program of a nuclear power plant.

Phase 1: siting. Responsibility: only NEPIO (no other organization allowed for this phase)
Phase 2: screening and ranking analysis, site, and technology selection. Responsibility: independent review committee under NEPIO. An operating organization and regulatory body are set up (IAEA 2012, 6)

The siting process is strongly linked to safety concerns and is therefore carried out by the nuclear regulatory framework, which should be in compliance with the IAEA Safety Guides on siting. However, in certain matters, cooperation and coordination with the
country’s government will be required in issues concerning “the protection of the environment, wildlife, cultural and historical heritages” (IAEA 2012, 15).

Infrastructure and siting considerations for SNF storage

The following considerations should be made for a SNF storage location:

- A dry and temperate climate
- Avoiding locations where natural disasters may occur by evaluating the possibility of earthquakes, flooding, volcanic outbreaks, examining seismology
- Avoiding locations prone to terrorism or hostile attacks
- Avoiding locations close to industrial sites
- Low population density (to ensure lower impact of emergency on population)
- Access to water for cooling (due to decay heat which can be transported to the environment from wet/dry storage facilities)
- Geology: considering co-location of disposal and storage (i.e., building the storage facility possibly somewhere where disposal could also be considered for the future), this way transport can be avoided (IAEA 2019b, 13-14)
- A good transport infrastructure is needed in case SNF is stored off the reactor site, for potential reprocessing or if a co-location of storage and disposal may not be possible
- Human resource capacity

Climate

With an altitude of 1000-1600 m above sea level Zambia has a relatively cool, sub-tropical climate with three seasons: “(i) a cool dry season between April and August; (ii) a hot dry season between August and November; and (iii) a hot wet season between November and April” (AUDA-NEPAD n.d., 11). Zambia’s weather conditions also vary by altitude (Central Intelligence Agency 2020).
**Population distribution**

Zambia is one of the most urbanized countries in sub-Saharan Africa, and the highest population densities can be found in Lusaka, Ndola, Kitwe, and Mufulira (Central Intelligence Agency 2020). 42.1 % of Zambia’s population is located in these urban regions. (Ministry of National Development Planning 2017, 35).

**Natural hazards**

High variability of climate conditions is the source of natural hazards such as droughts, tropical storms and floods in Zambia. The probability of floods and droughts is relatively high. Droughts also had a negative impact on the hydropower sector (Central Intelligence Agency 2020) (CIMA, UNDRR 2019, 28, 38). For the site selection process, it is important to take into account the probability of seismic hazards, volcanic explosions, droughts, and floods. These events could all have an impact not only on the facility infrastructure but also on other areas that the functioning of the facility might rely on, such as the rail infrastructure. While Zambia does not have any active volcanoes, there are some located in the South of Tanzania, at the Northern border of Zambia. However, the only volcano in Tanzania considered to be active is located in the north of the country and therefore has no impact on Zambia (Vye-Brown 2014, 1). The most recent earthquake in Zambia occurred three years ago, with a magnitude of 5,9 in Kaputa, northern Zambia. Most earthquakes that occurred in Zambia over the past 100 years were in the north, except for four events that occurred in the north-West, south-East, and central Zambia between 45 and 60 years ago (Earthquake Track 2020). Environmental issues in Zambia include air pollution (with acid rain being a consequence in locations of mining and refining activities), draining of chemicals into the watershed and a poor water infrastructure which affects human health and will be addressed in the following point (Central Intelligence Agency 2020).

**Access to water**

The Zambezi river flows along the border of Zambia and Zimbabwe, entering into Lake Kariba, which is created by the Kariba dam. The Kariba dam is the “largest man-made reservoir in the world [with] a height of 128m and with a crest length of 617m, the dam has the capacity of holding 181 billion cubic metres of water” (Darbourn, Kay 2015, 12).
The Kariba dam serves as a hydropower source for Zambia and Zimbabwe, as well as South Africa and Mozambique (Darbourn, Kay 2015, 13) (Central Intelligence Agency 2020). The stress on the country’s water resources has increased over the past years, as they are being exploited by agriculture, industry, and households. This is a consequence of a lack of research, development, and scientists concentrating on development concerns connected to water availability and infrastructure. With the Zambezi and Congo River basins, Zambia is rich in surface water resources. Nevertheless, the water infrastructure in Zambia is relatively weak. Water distribution, quality and resource problems, a lack of adequate infrastructure, an increase in water demand for energy and agriculture are the main issues that the country is dealing with in terms of water (AUDA-NPAD n.d., 10-15).

Transport infrastructure

A strong transport infrastructure can positively influence economic growth and industries wishing to locate in the given area, especially for a country like Zambia, that does not directly connect to maritime transport (Ministry of National Development Planning 2017, 77). The table below describes the modes of transport available in Zambia:

<table>
<thead>
<tr>
<th>Mode of transport</th>
<th>Details (length and location)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadways</td>
<td>Total: 67,671 km (2018)</td>
</tr>
<tr>
<td></td>
<td>Paved: 14,888 km (2018)</td>
</tr>
<tr>
<td></td>
<td>unpaved: 52,783 km (2018)</td>
</tr>
<tr>
<td>waterways</td>
<td>2,250 km (includes Lake Tanganyika and the Zambezi and Luapula Rivers) (2010)</td>
</tr>
<tr>
<td>River port</td>
<td>Mpulungu (Zambezi)</td>
</tr>
</tbody>
</table>

Human resource capacity

A further issue Zambia is facing in terms of development and socio-economic growth is a lack of human resources. The offered education does not match the skills required by the industry (Ministry of National Development Planning 2017, 84). This must be taken
into consideration for the nuclear sector, as it is of great importance to develop a country’s own human resources for a long term project like a nuclear power program.

3.1.3. Economic Criteria

This section will briefly touch upon the economic aspects of a nuclear power program, the country’s energy requirements, and energy mix. It is important to understand why the country is even considering nuclear power. Finally, the financing mechanisms will be addressed as well as questions deriving from contractual arrangements with vendors.

The economic criteria defined for this project include an illustration of the country’s energy demand, as economic growth, and an increased energy demand are correlated, general info on the country’s economy and financing mechanisms for the project, and thus for the waste management strategy.

- Energy demand: The need for nuclear power (increased energy demand, addition to energy mix)
- Economic situation
- Financing mechanisms for nuclear power program, waste management and reprocessing

Energy demand and nuclear power

The following section provides an overview of Zambia’s energy sector. Succeeding a brief overview, the country’s increased energy requirements will be touched upon which will help understand Zambia’s interest in nuclear power.

- 2,800 MW of installed electricity generation capacity
  - 85% of it is hydro based: 2,380 MW
  - 15% coal, heavy fuel oil, and other sources: 405 MW (US Aid 2020)
- 31% of the population has access to power (67% urban, 4% rural), 7,2 million households have no access (US Aid 2020)
- Goal for 2030: universal access to energy for the entire population and expansion of alternative energy sources by 15% (US Aid 2020) (Ministry of National Development Planning 2017, 72-73)

- Main operators: mainly ZESCO, state-owned and also some activity in the private sector (US Aid 2020)

With hydropower as its main source of energy, Zambia has experienced a deficit in energy production, due to insufficient investment (Ministry of National Development Planning 2017, 26) and droughts. Zambia’s electricity demand will grow by 150-200 MW yearly and peak at 3000 MW by 2020 (Ministry of National Development Planning 2017, 26) and 3,525 MW in 2030. With its extensive possibilities, Zambia would be able to provide double the amount of energy potentially demanded by 2020 (Ministry of National Development Planning 2017, 72-73). Economic growth in Zambia requires increased access to energy (US Aid 2020). Therefore, nuclear energy is being considered as an option to cover a fraction of the expected energy demand.

Economic situation

- Zambia’s economy relies on the copper industry and is therefore sensitive to fluctuating commodity prices (Ministry of National Development Planning 2017, 1-2)

- Zambia has a GDP of $26,72 billion (The World Bank Group 2019)

- Average economic growth (Ministry of National Development Planning 2017, 1-2)
  - 2000 to 2005: 5.8% per year
  - 2006 to 2015: 6.9%.

The economic growth in the past years did not create enough new jobs and therefore, could not have a positive impact on poverty reduction. Employment opportunities are crucial for economic growth (Ministry of National Development Planning 2017, 3). Global integration has advantages for the country and has been listed as a decisive factor for Zambia’s economic growth (Ministry of National Development Planning 2017, 36). However it can be accompanied by a number of disadvantages: “The greater the level of integration or interdependence among countries, the greater the potential for a number
of risks, such as political turmoil, migration, trade imbalances, illicit trade, infectious diseases and the effects of climate change” (Ministry of National Development Planning 2017, 36). The infrastructure, water supply, transportation, as well as research, development, science and technology must yet be enhanced for economic growth (Ministry of National Development Planning 2017, 11, 62).

Financing mechanisms

Managing radioactive waste is a costly process, usually, billions of dollars are required. The largest fraction of these costs is made up of the management of HLW. However, these costs are merely a small percentage of income from electricity generation. The most commonly chosen payment mode is that the waste generator pays for the waste with the revenue from selling the electricity. This mode of payment is suitable for short-term operations. The financing of radioactive waste over a longer time scale requires additional funding mechanisms. Factors that might influence the costs are a shift in policies and regulations, research and development, investment in newer technologies, multinational solutions and discount rates (NEA 1996, 77, 79). Concerning the costs for long-term storage, it is important to plan in advance in order to avoid difficulties in financing the long-term storage facility. If the long-term storage facility is built on-time, when the plant is commissioned, the costs can be covered by the operator of the nuclear power plant. If the initial investments for construction are made by the operator, the ongoing costs for maintaining storage facilities should not pose a problem. Even on a long-term basis, these should not be too high and therefore, manageable. The timespan between the commissioning of the plant and the final decision to build a disposal facility can be very long, therefore the question of financing such a facility can be accompanied by numerous difficulties, especially for developing countries. If the disposal facility is not financed by the operator of the plant or by another investor, it might not be possible to envision this possibility. As the example of Finland illustrates, considering deep geological disposal requires years of research and is thus a costly process. In some countries, a fraction of income from the operation of the plant is saved in a fund, which has the purpose of financing a disposal facility in the future (NEA 1996, 80-81).

As can be retrieved from the information in table 6, Rosatom is financing the construction of a research reactor and a nuclear power plant in Zambia. Rusatom Overseas is a
company belonging to the Rosatom State Corporation group, which manages all of the international projects that Rosatom is involved in. For example, the planned nuclear power plant in Egypt will be run for ten years by Rosatom and will then be handed over to the country itself (Rosatom 2020a). In the case of Zambia, it is not yet clear how long the vendor will run the plant. Rusatom Overseas state that they support their customer countries in financing and developing solutions for SNF handling and reprocessing (RAOS JSC 2016). In order to evaluate whether the arrangement is feasible for a country like Zambia, further insight into the contract is required. If such insight is provided, the following questions must be answered:

- Waste management strategies and approaches can be changed over the years. If further financing is required for this reason, will it be provided by the vendor, in case the customer country does not have the capacity to do so?

- Human resources are required for all operations connected to the project, and Zambia is low in skilled labor force. Will a financing mechanism for training (possibly abroad) be offered by the vendor?

- If disposal is a possibility and the prerequisites are met by Zambia, will a financing mechanism for a future disposal facility be possible?

- As part of a nuclear power project, also a waste management facility might require major investments in infrastructure. Are these investments taken care of as components of the project financing?

3.2. Interview

The following interview with Dr. Reuben Katebe, the National Coordinator for the Nuclear program in Zambia, will provide an indispensable insight and answers to open questions from the precedent chapters.

Membership to the treaties and agreements addressing nuclear issues

Zambia is a member of SADC (Southern African Development Community). What influence does SADC have on Zambia’s future nuclear platform and their nuclear waste management strategy?

Answer: Yes. Zambia is a member of SADC and therefore, SADC has great influence on Zambia’s nuclear program. Currently, there is no common SADC nuclear waste
management strategy, but each individual country has to meet the international requirements to operate a nuclear power plant.

*What consultations is Zambia making/going to make concerning the provisions of the Pelindaba treaty (in terms of nuclear waste management)?*

Answer: Yes. Zambia is signatory to the treaty and will abide by its entire requirement, in particular concerning the issue of nuclear weapon production. Zambia’s nuclear program is for peaceful applications.

**Political situation and public acceptance**

*Who is responsible for radioactive waste disposal? Which government entity? Is ZAMATOM (Zambia Atomic Energy Corporation) responsible for radioactive waste disposal?*

Answer: According to the Nuclear Policy being developed by ZAMATOM, there will be an independent institution responsible for waste management.

*For which government entity is the success of such a project the most important?*

Answer: Most likely the ministry dealing with environmental issues will be most appropriate to undertake waste management responsibilities.

*Which (government) entities or NGOs have the biggest influence on the project and which are skeptical?*

Answer: At the moment, it is difficult to categorize since most of the comments for or against the nuclear program are coming from individuals through the press and other form of social media.

*Who is most affected?*

Answer: The people who were against the construction of the Centre were those who had encroached on the piece of land for the project.
Does this concern the research reactor?

Yes. This concerns the site where the research reactor will be housed.

Who is for/against the project, and who can convince?

Answer: The local leadership can be a help to convince the locals on the safety of the Centre.

In Zambia, there is a lot of willingness to build a Nuclear power plant: Has there been a poll? How was public enthusiasm for this project encouraged?

Answer: No! a project concept note will be submitted to the IAEA for support for public acceptance campaigns. At the end of the public awareness campaigns, most likely a poll will be conducted.

Is nuclear waste management going to be addressed in the public acceptance campaign or has it already been addressed?

Answer: Yes. Although it has being discussed that the waste from the research reactor will be shipped back to the supplier. However, going forward, Zambia has to develop capacity to manage its wastes arising from nuclear applications. This is one issue which will be subjected to debate for Public Acceptance.

Are terrorism threats an issue in Zambia? Must anything in particular be considered in safety and security?

Answer: No! The government will assign the Army to protect all nuclear facilities.

Human resources

Can the labor force be provided within the country?

Answer: They have to develop their own, at present they definitely need from outside. It depends on the contractual arrangements. For intermediate they definitely do.
Could you further elaborate which kind of labor force must be brought from the outside and how the labor force will be developed?

Answer: To begin the program, the vendor will provide skilled labor to operate the plant until such a time when trained Zambians will acquire experience and skills. Currently, the government has developed a robust human resource development in nuclear science and technology. Scholarships are awarded to students annually at both undergraduate and post graduate level to study in Russia.

**Financing**

What are the financing options Zambia has considered for the nuclear power program (trainings, building of NPP, changes in infrastructure)?

Answer: Training is being financed through government scholarships. For a NPP the option being considered is Build Operate Transfer, looking at the amount of money involved. The financing option for the upgrading of the infrastructure will be done as part of the financing package for the NPP.

**Contractual arrangements with the provider**

2018 Rosatom and Zambia signed a contract for building a Center for Nuclear Science and Technology in Chongwe – is the location also suitable for a NPP? If not, in which city in Zambia could a NPP be built?

Answer: The site in Chongwe district is not suitable for the NPP and the government is consulting experts on the location of the NPP.

According to the IAEA Safety Series (SSG-15), the regulatory body is responsible to verify that the operating organization is providing the necessary personnel and the technical and financial resources for the lifetime of the spent fuel storage facility. Has for the case of Zambia already been decided what will be done with the spent fuel from the NPP and who will take care of it during and after Rosatom is running the plant?
Answer: No. The decision has not been taken on spent fuel storage but there is a proposal that spent fuel are sent back for reprocessing into useful materials. An institution will be formed to take care of all nuclear wastes from the facilities.

**Infrastructure**

*How much of the energy is planned to be covered by nuclear? (from this number an approximation of the amount of waste can be calculated)*

Answer: It is planned that two 1200 MW Nuclear power plants will be built to start with.

*Which potential locations would be chosen for the construction of the NPP?*

Answer: Preliminary remote sensing site selection exercise, five sites have been identified in the northern part of Zambia. Detailed studies will be done to select one.

*Which would be suitable for the storage facility (in case waste is stored off-site)? (interim and long-term storage)*

Answer: Currently, the radiation protection authority operates an interim storage facility for spent radioactive sources. Plans are under way to establish a permanent site for radioactive sources in Zambia.

Zambia has suitable locations for deep geological storage (granite reserves in Luapula, Northern, Muchinga, Southern, and Eastern Provinces, several clay deposits) throughout the country and salt deposits in the South. Would a deep geological disposal facility be an option?

Answer: This remains an option. However, detailed considerations before a final decision is taken. I support deep geological disposal, especially if the closed underground mines can be used by turning them into disposal facilities.

**3.3. Qualitative assessment of goal attainment**

The following table provides a qualitative assessment of goal attainment in terms of preparedness of Zambia for radioactive waste management. The table includes selective
criteria that are indicative of the country’s status. Based on the findings in the case study and interview, each criterion is given a score of high, medium or low. Under ideal considerations, the overall score should be at least medium. Zambia has scored “medium” and “high” in three categories, respectively, and “low” in only two. Therefore, Zambia’s score is in a range between “medium” and “high”. As a further step a quantitative assessment is suggested.

**Table 10: Qualitative assessment of goal attainment for radioactive waste management**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safeguards</td>
<td>High</td>
<td>Zambia is a party to the “Treaty on Non-Proliferation of Nuclear Weapons” and the “Treaty of Pelindaba”</td>
</tr>
<tr>
<td>Financing</td>
<td>Medium</td>
<td>Zambia itself does not have the means to finance the project and is relying on a vendor</td>
</tr>
<tr>
<td>Technical (site selection)</td>
<td>Low</td>
<td>Site selection has not been done yet</td>
</tr>
<tr>
<td>Human resources</td>
<td>Low</td>
<td>Zambia has yet to develop their human resources</td>
</tr>
<tr>
<td>Political stability</td>
<td>High</td>
<td>Zambia is considered one of the most stable countries in Africa</td>
</tr>
<tr>
<td>Legal framework</td>
<td>Medium</td>
<td>Zambia has yet to establish a regulatory body.</td>
</tr>
<tr>
<td>Agreements</td>
<td>Medium</td>
<td>Zambia has to apply for accession to the Joint Convention</td>
</tr>
<tr>
<td>International cooperation</td>
<td>High</td>
<td>Zambia is a member of the IAEA</td>
</tr>
</tbody>
</table>
4. Conclusion and recommendation

The case study conducted in the previous section explores a strategic approach for the evaluation of a country’s ability to handle the SNF generated from a nuclear power plant. A country’s capability to handle its radioactive waste depends on several factors and requires the implementation of certain measures. A brief overview is provided by the subsequent figure, which shows the interconnected criteria, the factors which they depend on, and what is further required and recommended for their implementation.

![Flowchart](Figure 6: Flowchart)

In the case of Zambia, the following conclusions can be made from the case study:

Concerning the legal criteria, Zambia benefits from its political stability, the government’s support for the nuclear power program as well as the membership to the
IAEA, AFRA, and SADC. It is however recommended that Zambia applies for accession to the Joint Convention. For technical criteria, certain design measures must be met, which are interconnected with the measures for safety, security, and safeguards. The technical criteria depend on the type of fuel cycle chosen and storage possibilities. As can be retrieved from the interview, Zambia is considering a reprocessing option with shipment to Russia - this option is favored by the international community due to safeguards reasons, as it is easier to monitor the reprocessing in one location (in this case Russia), rather than several different ones. In terms of security, Zambia can again profit from its political stability and the fact that terrorism is not considered a threat to the country. Site selection is highly dependent on factors, which, for the most part, cannot be influenced. As a consequence, they must be evaluated carefully before a site is chosen. A final recommendation for a possible site is out of the scope of this paper, and as mentioned in the interview, this will be a lengthy process requiring a team of experts. Therefore, organizational guidance by an organization such as the NEPIO is highly recommended for countries implementing nuclear power programs. Due to its economic growth, Zambia meets the requirements to justify considering an additional energy option, such as nuclear. Zambia can manage to finance the project with the aid of a vendor, in this case, Rosatom. It is recommended that the contractual arrangement with the vendor incorporates not only initial investment costs such as the construction of the facility. Future related financial matters, such as the financing of decommissioning and the long-term storage and final disposal of radioactive waste must be addressed as well in the contract. Zambia’s compliance with the criteria for radioactive waste management are being met to the extent that is possible to examine with the information currently available. Further research must be done in areas such as site selection and possibilities for deep geological disposal. It is recommended that Zambia follows the recommendations and guidance provided by the IAEA, establishes a radioactive waste management strategy and reviews the contractual arrangements with an independent body in order to evaluate its feasibility.
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