MSc Program
Environmental Technology & International Affairs

Nuclear Renaissance in Sub-Saharan Africa and the Demands of Emergency Preparedness. With a Case Study of Ghana

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

supervised by
Dr. Kaluba Chitumbo

Anja Vujaković, BA

01549648

Vienna, 10.10.2023

Affidavit

I, **ANJA VUJAKOVIĆ, BA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "NUCLEAR RENAISSANCE IN SUB-SAHARAN AFRICA AND THE DEMANDS OF EMERGENCY PREPAREDNESS. WITH A CASE STUDY OF GHANA", 100 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.

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Abstract

In the context of burgeoning nuclear renaissance in sub-Saharan Africa, an important nuclear safety question arises: do nuclear newcomer countries in the region have the capacity to develop a robust nuclear emergency preparedness and response infrastructure, and what are the challenges? With this question in mind, this master thesis encompasses five distinct research steps. Firstly, it identifies challenges that are specific to the region of sub-Saharan Africa and assesses their prevalence in the nuclear frontrunner countries. Secondly, it identifies and explores key requirements for nuclear emergency preparedness and response infrastructure outlined by the International Atomic Energy Agency (IAEA). Subsequently, it derives vital regional requirements that are missing from the IAEA's portfolio and combines them with IAEA requirements to create a weighted assessment model for nuclear emergency preparedness and response capabilities in countries of sub-Saharan Africa. Lastly, it undertakes a comprehensive case study focusing on the Republic of Ghana. The findings indicate a high prevalence of region-specific challenges in all nuclear frontrunner countries in sub-Saharan Africa and a mismatch between their nuclear ambitions and their performance in key development aspects such as economic health, basic infrastructure, and political stability. The results of the case study on Ghana indicate below-average nuclear emergency preparedness and response capacity and offer valuable insights into key areas for improvement. The thesis concludes with a summary of key findings and practical recommendations for addressing identified challenges, providing a valuable resource for relevant authorities.

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List of abbreviations

AIDS	Acquired immunodeficiency syndrome
CIA	Central Intelligence Agency
EAL	Emergency action level
EP	Emergency preparedness
EPR	Emergency preparedness and response
EPREV	Emergency Preparedness Review
ER	Emergency Response
Euratom	European Atomic Energy Community
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GAEC	Ghana Atomic Energy Commission
GDP	Gross domestic product
GHARR-1	Ghana Research Reactor 1
GNPPO	Ghana Nuclear Power Programme Organisation
GSR	General Safety Requirement
HIV	Human immunodeficiency virus
IACRNE	Inter-Agency Committee on Radiological and Nuclear Emergencies
IAEA	International Atomic Energy Agency
ICS	Incident Command System
ICRP	International Commission on Radiological Protection
IEA	International Energy Agency
INES	International Nuclear and Radiological Event Scale
INIR	Integrated Nuclear Infrastructure Review
IRENA	International Renewable Energy Agency
ITU	International Telecommunication Union
MPPN	Multidimensional Poverty Peer Network
MOU	Memorandum of understanding
NADMO	National Disaster Management Organization
NDMP	National Disaster Management Plan
NGO	Non-governmental organization
NNRERP	National Nuclear and Radiological Emergency Response Plan

NPG	Nuclear Power Ghana
NPI	Nuclear Power Institute
NRA	Nuclear Regulatory Authority
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
OECD/NEA	OECD Nuclear Energy Agency
OIL	Operational intervention level
PAZ	Precautionary action zone
RPB	Radiation Protection Board
RPI	Radiation Protection Institute
Rosatom	State Atomic Energy Corporation Rosatom
SDG	Sustainable Development Goal
TSO	Technical and Scientific Support Organization
UN DESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
UNDRR	United Nations Office for Disaster Risk Reduction
UNSD	United Nations Statistics Division
UPZ	Urgent protective action planning zone
US	United States of America
USIE	Unified System for Information Exchange in Incidents and Emergencies
WHO	World Health Organization
WMO	World Meteorological Organization
WNN	World Nuclear News
WWII	World War II
WASH	Water Supply, Sanitation and Hygiene

Acknowledgements

I would like to thank Dr. Kaluba Chitumbo, my thesis advisor, for his patient mentorship and guidance which were instrumental in shaping this thesis. Likewise, I acknowledge the generous support from Mag. Isabelle E. Starlinger and Prof. Hans Puxbaum.

I extend my heartfelt appreciation to Mr. Lennox Assan for his invaluable support and dedicated efforts in facilitating communication with the Nuclear Regulatory Authority in Ghana. His enthusiasm and personal investment of time greatly aided my research.

Furthermore, I am thankful to Neo Culture Technology for their continuous delivery of inspiration and motivation. Their innovative spirit and commitment to excellence have driven me to uphold the highest standards of achievement.

I owe my deepest thanks to Anna Sofia Koivu and Janny van Dorst for their constant encouragement and belief in my abilities. Likewise, my heartfelt thanks go to Jodie Tweddell, Esther Ho, Rebeka Pap, Joscelyne Cole, Marisa McDonald, and Karoline Welser whose camaraderie was a driving force throughout.

I would also like to extend my heartfelt gratitude to my dear study colleague Alrae Kieron Ramsey whose words continue to inspire me. May he rest in peace.

My sincere thanks go to Dr. Pius Jungblut for his efforts and shared dedication to the success of my academic journey and my well-being.

Lastly, I extend my most earnest appreciation to Željka Dabić, my mother, whose unwavering dedication and support were most valuable. Thank you.

1. Introduction

In a decade marked by a budding nuclear renaissance in sub-Saharan Africa, the role of nuclear emergency preparedness and response (EPR) infrastructure comes into sharp focus. Across the region, a number of countries have expressed their determination to introduce nuclear power into their energy mix, even as they navigate the challenges of underdeveloped basic infrastructure, political instability and economic constraints. Seeing as sub-Saharan Africa is one of the regions in the world most vulnerable to external shocks due to its unique developmental landscape, the importance of a robust nuclear emergency preparedness and response network become even more evident. However, the region's unique needs are not recognized in the existing body of literature and are not addressed in IAEA's guides and manuals. Herein lies the primary motivation for this study.

The thesis will consist of five parts with distinct research steps. The first part will examine the unique set of challenges sub-Saharan Africa confronts which are relevant for nuclear EPR considerations and which distinguish the region from the rest of the nuclear world. Additionally, the prevalence of identified challenges in nuclear frontrunner countries in sub-Saharan Africa will be assessed and discussed. Moving forward, the second part will delve into general, functional and infrastructural requirements for nuclear EPR outlined by the IAEA, identifying and examining key elements. Subsequently, the third part will introduce a new set of regional requirements derived from specific challenges identified in the first part of the thesis. Moreover, the newly introduced requirements will be combined with those of the IAEA in order to craft a single-country weighted assessment model for nuclear EPR in sub-Saharan Africa, in the fourth part. The final part of the thesis will consist of a case study, examining the state of the nuclear EPR infrastructure in the Republic of Ghana by applying the weighted assessment model. The aim of this study is to provide a realistic snapshot of Ghana's nuclear EPR capability in the year of 2023 as well as identify priority areas for improvement. Lastly, the summary of findings as well as a list of recommendations for policy-makers, local nuclear authorities and international organizations will be provided.

The methodology employed in the course of the thesis comprises of comprehensive literature analysis, analysis of data-sets published by international organizations, primary data collection through self-administered questionnaires and interviews, as well as the creation of a weighted assessment model to evaluate nuclear EPR capabilities of specific countries.

By identifying and examining challenges that are specific to sub-Saharan Africa, and creating a weighted assessment model, this study can contribute to better understanding of unique needs of nuclear newcomer countries in the region as well as the areas that require greater focus in the future. Additionally, it could be a useful tool for governments, NGOs and international organizations who are providing support and assistance to the region on its nuclear journey.

2. Literature review

The current pool of available literature on nuclear emergency preparedness and response consists almost exclusively of IAEA-issued safety standards, manuals, guides, and training materials, which is logical given its role as a central global authority on nuclear power and technology. In 2007, the IAEA developed its famous 'Milestones Approach' – a prominent publication serving as a manual for countries pursuing nuclear power projects for the first time. It lists nineteen infrastructural areas which must be considered, emergency preparedness being one of them. However, there are not more than two pages of text dedicated to this complex issue in the most recent version of the publication. (IAEA, 2015c)

Similarly, for many years after, IAEA literature dedicated to emergency preparedness remained scarce, limited to a few manuals mostly focusing on medical and communication aspects of EP. In the aftermath of Fukushima Daiichi Accident, a larger influx of EP literature was seen for the first time, with nine new publications released in 2012 and 2013 alone. As of July 2023, there 33 publications in total relating to EP, however, only four or them – or 12% – are intended for nuclear newcomer countries and thematize the initial stages of EPR infrastructure development. (IAEA, 2023d)

Out of these four publications, two are more recent and focus on specific areas of EPR infrastructure. The 2015 "Method for Developing a Communication Strategy and Plan for a Nuclear or Radiological Emergency" serves as a guide for nuclear newcomer countries on how to develop national radiation emergency plans, whereas 2021 “Considerations in the Development of a Protection Strategy for a Nuclear or Radiological Emergency” provides guidance on how to develop and optimize protection strategies for nuclear and radiological emergencies. (IAEA, 2015b; 2021) The remaining two publications could be viewed as pivotal for nuclear newcomers as they address all aspects of EPR and focus on initial development stages. Nevertheless, they are 11 and 20 years old, respectively. The 2003 “Method for Developing Arrangements for Response to a Nuclear or Radiological Emergency” has served as an essential resource for countries embarking on nuclear journeys, however, it is based on outdated safety standards. The 2012 “Considerations in Emergency Preparedness and Response for a State Embarking on a Nuclear Power Programme” has also been an indispensable resource, yet it was also published before the most recent update of IAEA’s EPR Safety Requirements in 2015. (IAEA, 2003; 2012a) Additionally, it should be noted that all four of these publications were developed based on experiences of veteran nuclear countries, which have predominantly been developed or high-income developing countries, and may therefore not be entirely suited for nuclear newcomers with lower development indicators. Although countries in sub-Saharan Africa may eventually make use of such literature, their current needs are more basic and seemingly not supported by the existing body of literature.

In addition to aforementioned guides and manuals, two further IAEA publications are of high importance, both part of its Safety Standards Series: The 2007 “Arrangements for Preparedness for a Nuclear or Radiological Emergency: Safety Guide” commonly referred to as ‘GS-G-2.1’ and the 2015 “Preparedness and Response for a Nuclear or Radiological Emergency” commonly referred to as ‘GSR Part 7’. (IAEA, 2007; 2015d) These two publications serve as de facto global standard for EPR safety requirements and represent an authoritative reference for all nuclear newcomer countries.

When it comes to nuclear EPR literature focusing on sub-Saharan Africa, the available resources are also limited. A comprehensive search across various academic databases and search engines revealed a modest body of literature largely focusing on the status of nuclear power development in a general sense, not examining EPR specifically. Additionally, while there is some literature on EPR in South Africa, its relevance for other countries in sub-Saharan Africa is marginal due the country’s higher development level in the years leading up to the nuclear power deployment as well as the significant temporal gap. Moreover, changes in international safety standards, safety requirements, and technological advancements over time have further decreased its applicability for current research and practical use in the region.

Given the limitations of available literature, there is a compelling need for focused research on specific challenges of nuclear newcomer countries in sub-Saharan Africa relating to the development of nuclear emergency preparedness and response infrastructure. This master thesis aims to address this gap.

3. Sub-Saharan Africa and nuclear EPR demands

Just as Europe is divided into Northern, Eastern, Southern and Western Europe, the African continent is divided into two separate geographic regions by the United Nations Statistics Division: Northern Africa and **sub-Saharan Africa**. Sub-Saharan Africa is considered to be "*the region of Africa to the south of the Sahara Desert*". (Collins English Dictionary, 2023) This includes all countries that are fully and some that are partially located south of the Sahara Desert – some international organizations differ slightly in which countries they include in the list[1]. Although exceptionally diverse, both in terms of culture as well as demography and geography, sub-Saharan Africa still showcases a certain level of homogeneity in relation to Northern Africa, which is why the term continues to be used by international organizations. (L.T., 2023)

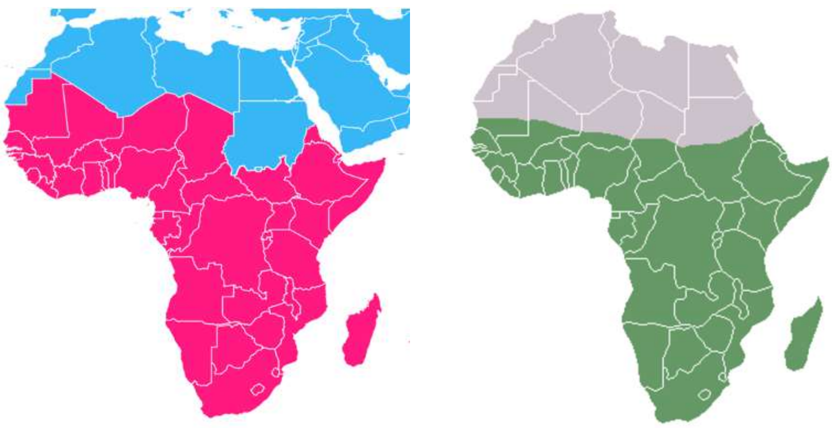

Figure 1: Political map of sub-Saharan Africa with the addition of ecological break (United Nations, 2023b)

[1] The United Nations Statistics Division lists 53 countries as part of sub-Saharan Africa (UNSD, 2023)

The following chapters will examine the history of energy demand and electricity needs in sub-Saharan Africa which prompted the nuclear renaissance in the region, as well as the development of nuclear capabilities and the specific nuclear emergency preparedness challenges and needs that arise from the region's unique socioeconomic and geopolitical circumstances. Combined findings from chapters 3, 4, and 5 will serve as a basis for the development of a weighted assessment model for nuclear EPR capability of single countries in sub-Saharan Africa that will ultimately be applied during the case study on the Republic of Ghana, in chapter 7.

3.1. Nuclear renaissance in sub-Saharan Africa

The turn of the century brought about growth of astounding rate in sub-Saharan Africa. Major economic and sociopolitical shifts took place across the region. Many countries begun transitioning towards democracy, thereby improving general governance. Armed conflicts lessened and the economic growth picked up and steadied. Positive development has been seen in a variety of sectors such as finance, health, agriculture, housing, communications, technology, digitalization, education etc. All these factors have led to rapid urbanization and a significant growth of the middle class. (UNDP, 2020)

This shift was accompanied by an unprecedented energy demand on the continent. However, as the world is in the midst of a climate crisis, Africa is faced with a considerable challenge – meeting its growing energy demands by ensuring a *reliable, cost-effective,* and *sustainable* energy supply. According to the World Bank data, 50,6% of population in sub-Saharan Africa had access to electricity in 2021. (IEA et al., 2023) It has become a priority of most governments in the region to achieve universal electricity access in order to enable further economic and human development. However, ensuring all households have access to electricity is only part of the picture. Main target of the Sustainable Development Goal 7 (SDG7) is to "*by 2030, ensure universal access to affordable, reliable and modern energy services*" (United Nations, 2023d) The primary indicator focuses on households and the threshold for electricity access is set very low – even households who are only able to keep basic lighting running are considered to have electricity access. Whereas ensuring this kind of access is an important milestone, it is not enough to sustain economic growth and keep up with the development demands.

A non-profit global network of researchers, advocates, and policymakers – the Energy for Growth Hub – has coined a new term that builds on SDG7. 'Modern Energy Minimum' raises the current threshold of roughly 50-100kWh per person per year to 1,000 kWh per person per year. Out of this amount, 300 kWh are meant for residential consumption whereas the additional 700 kWh are meant for consumption in the wider economy (e.g., by industries or communal facilities). (Moss et al., 2021)

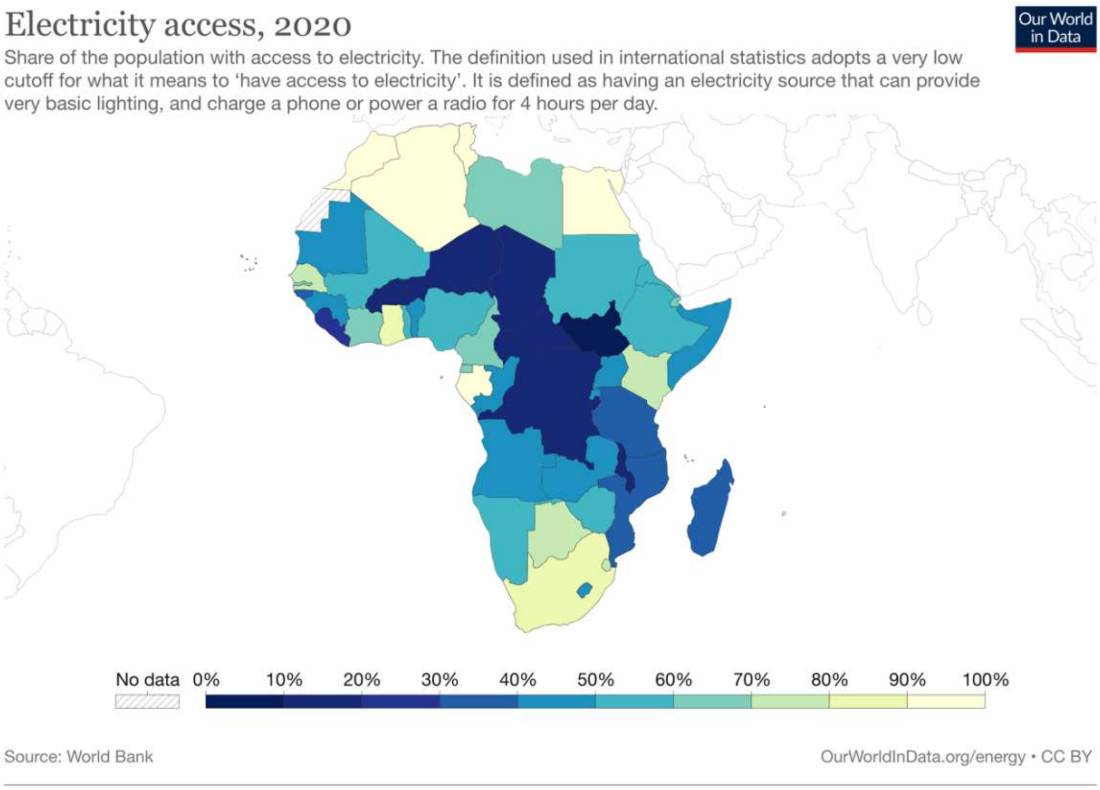

Figure 2: Electricity access in Africa, 2020
(World Bank, 2023a)

Considering the Modern Energy Minimum and the rapid population growth in sub-Saharan Africa[2], reliable, cost-effective, and sustainable energy supply is number one condition for future prosperity which is why many countries are considering nuclear energy solutions. In addition to South Africa who has been operating a commercial nuclear power reactor since 1984, four other countries have taken major steps towards developing nuclear infrastructure and are aiming to be ready by 2030s: Ghana, Kenya, Nigeria, and Sudan. Additional seventeen countries have expressed interest and have taken initial steps towards developing nuclear capabilities, Uganda, Rwanda, Niger and

[2] Expected additional number of Africans by 2050 is 1,3 billion. (UNDP, 2020)

Zambia having the most ambitious goals. (Kincer and Lovering, 2023) Table 1 shows which key steps have been taken by each nuclear *newcomer* country, based on self-research of press-releases and public announcements in each of the countries[3].

Table 1: Steps taken towards developing nuclear infrastructure per country in sub-Saharan Africa

Country	Formal policy authority	Hard MOU	Substantial progress on IAEA milestones	Formal Regulatory Authority	Policy document: nuclear intention	Soft MOU or engagement with IAEA milestones
Ghana	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Kenya	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Nigeria	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Sudan	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Angola	No	No	No	Yes	No	Yes
Botswana	No	No	No	Yes	No	Yes
Burkina Faso	No	No	No	Yes	No	Yes
Chad	No	No	No	Yes	No	Yes
Cote d'Ivoire	No	No	No	Yes	No	Yes
Democratic Republic of the Congo	Yes	No	No	Yes	No	Yes
Ethiopia	No	No	No	Yes	No	Yes
Malawi	No	No	No	Yes	Yes	Yes
Mauritania	No	No	No	Yes	No	Yes
Namibia	No	No	No	Yes	Yes	No
Niger	Yes	No	No	Yes	No	Yes
Rwanda	No	No	Unclear	Yes	Yes	Yes
Senegal	No	No	No	Yes	No	Yes
Tanzania	Yes	No	No	Yes	Yes	Yes
Uganda	Yes	No	No	Yes	No	Yes
Zambia	Yes	No	No	Yes	Yes	Yes
Zimbabwe	No	No	No	Yes	No	Yes

Source: Format partially adapted from (Kempfer et al., 2020)

[3] South Africa has not been included in the table as it has been operating a nuclear power plant since 1984 and is therefore not a nuclear *newcomer* country.

Developing nuclear capabilities is a significant challenge even for high-income countries. Immense financial, institutional, and technological resources are required to prepare for and successfully run a nuclear energy program. A significant fraction of these efforts needs to be dedicated to developing a *nuclear emergency preparedness and response infrastructure* – an undertaking that comes with a unique set of challenges in sub-Saharan Africa that have not been given due consideration in IAEA's guides and manuals. Unsurprisingly, given the nuclear newcomers status[4], there is a severe lack of literature on specific nuclear EPR needs in the sub-Saharan region at the moment. However, since numerous points of intersection exist between conventional and nuclear emergency preparedness, the following chapter will identify and examine region-specific challenges based on findings from conventional emergency preparedness literature and link them to the demands of nuclear EPR infrastructure.

3.2. Region-specific challenges for nuclear emergency preparedness and response in sub-Saharan Africa

The rapid growth in sub-Saharan Africa described in the previous chapter has not been a result of equal contributions from each country. Some countries have experienced tremendous growth while others remain afflicted by conflict, poverty, and underdevelopment. As of 2021, 45% of countries in sub-Saharan Africa[5] belong to the middle-income category as per World Bank's classification. Many of them obtained this status in the past decade. (World Bank, 2023b) Particularly urban regions in middle-income economies are facing a magnitude of challenges and obstacles that accompany rapid economic and population growth. Energy poverty, inadequate infrastructure, natural and man-made disasters, political instability, and skills shortage are only some of the issues governments are facing. (UNDP, 2020)

Given the challenging external environment, development of a nuclear emergency preparedness and response infrastructure in sub-Saharan Africa is subject to requirements that extend beyond those identified by the IAEA. After extensive review of literature addressing *conventional* emergency preparedness on the African continent, the following five challenges could be identified that will require particular attention in addition to all

[4] With the exception of South Africa
[5] 24 out of 53 countries

the general, functional, and infrastructural requirements[6] for nuclear EPR detailed in IAEA's guides and manuals:

- Political instability
- Poor economic performance
- Human capital deficiencies
- Weak health systems performance
- Basic infrastructure deficit

The following chapters will provide a closer look at each of the five challenges and explain their relevance for nuclear EPR considerations. These insights will then be used to formulate an additional set of requirements for sub-Saharan Africa that builds on requirements already established by the IAEA. Ultimately, this newly proposed set of requirements will serve as the basis for a single-country weighted assessment model introduced in chapter 6.

3.2.1. Political instability

Five index-based models to measure political instability developed by the Frederick S. Pardee Center for International Futures rely on data from the following fields identified as drivers of instability: *demographics, development, governance, structural imbalances, and horizontal inequalities*. The results obtained through the five models give rise to both optimism and concern since some models uncover positive and others negative trends in the region. A joint 2018 report by the Institute for Security Studies and Frederick S. Pardee Center for International Futures shows that the overall political instability in Sub-Saharan Africa has declined in the past decades yet remains high when compared with the global average and particularly high when compared with regions consisting of predominantly developed countries – regions that have historically been home to nuclear newcomer countries. (Bello-Schünemann and Moyer, 2018)

Although *demographic risk* in sub-Saharan Africa has continuously been on a downward trend, it still remains a significant driver of political instability in the region. 19 out 20 countries with the highest population growth rate in 2023 are located in sub-Saharan

[6] See chapters 4.2.-4.4.

Africa. (Statista, 2023) Both countries with large population and countries with rapidly increasing population are at a higher risk of developing political instability since population growth is accompanied by competition for land and resources, particularly when distribution of said resources is managed poorly. Large populations often mean higher number of ethnic or religious subgroups within the country which again increases the risk of political instability, such is the case in Nigeria. This risk can be mitigated through good governance and strong institutions – both of which are lacking in most parts of sub-Saharan Africa. Additionally, countries with large youth bulges[7] are associated with higher political instability, particularly when coupled with a low human capital development and high horizontal inequalities, which is yet again the case for most countries in sub-Saharan Africa, Kenya being a prime example. (Bello-Schünemann and Moyer, 2018)

Regime types are one additional factor that has a significant effect on political (in)stability. Historically, anocracies[8] have shown a very strong destabilizing quality and it comes as no surprise that most regimes in sub-Saharan Africa are indeed anocracies. According to the Economist Intelligence Unit's Democracy Index 2022, the four most serious nuclear newcomer countries in the region can be classified as follows:

- Ghana: flawed democracy with a score of 6,43
- Kenya: hybrid regime (anocracy) with a score of 5,05
- Nigeria: hybrid regime (anocracy) with a score of 4,23
- Sudan: authoritarian regime with a score of 2,47

Source: (Economist Intelligence Unit, 2023)

All countries in sub-Saharan Africa that have expressed interest in developing nuclear power infrastructures will have to, among other efforts, significantly invest in democratization processes in order to create a political environment that is stable enough to host a nuclear power plant. Out of 434 operational nuclear power reactors in the world, 284 or 65,44% are located in high-income OECD countries which score significantly higher on all indicators for good governance. (IAEA, 2022c). Figure 3 provides a

[7] i.e., countries where youth (15-24 years) constitutes more than 10-15% (OECD average). (Urdal, 2011)
[8] Regimes with mixed democratic and authoritarian elements (Marshall and Elzinga-Marshall, 2017, p.30)

comparison between sub-Saharan Africa and high-income OECD countries on 6 different governance indicators, as measured by the World Bank.

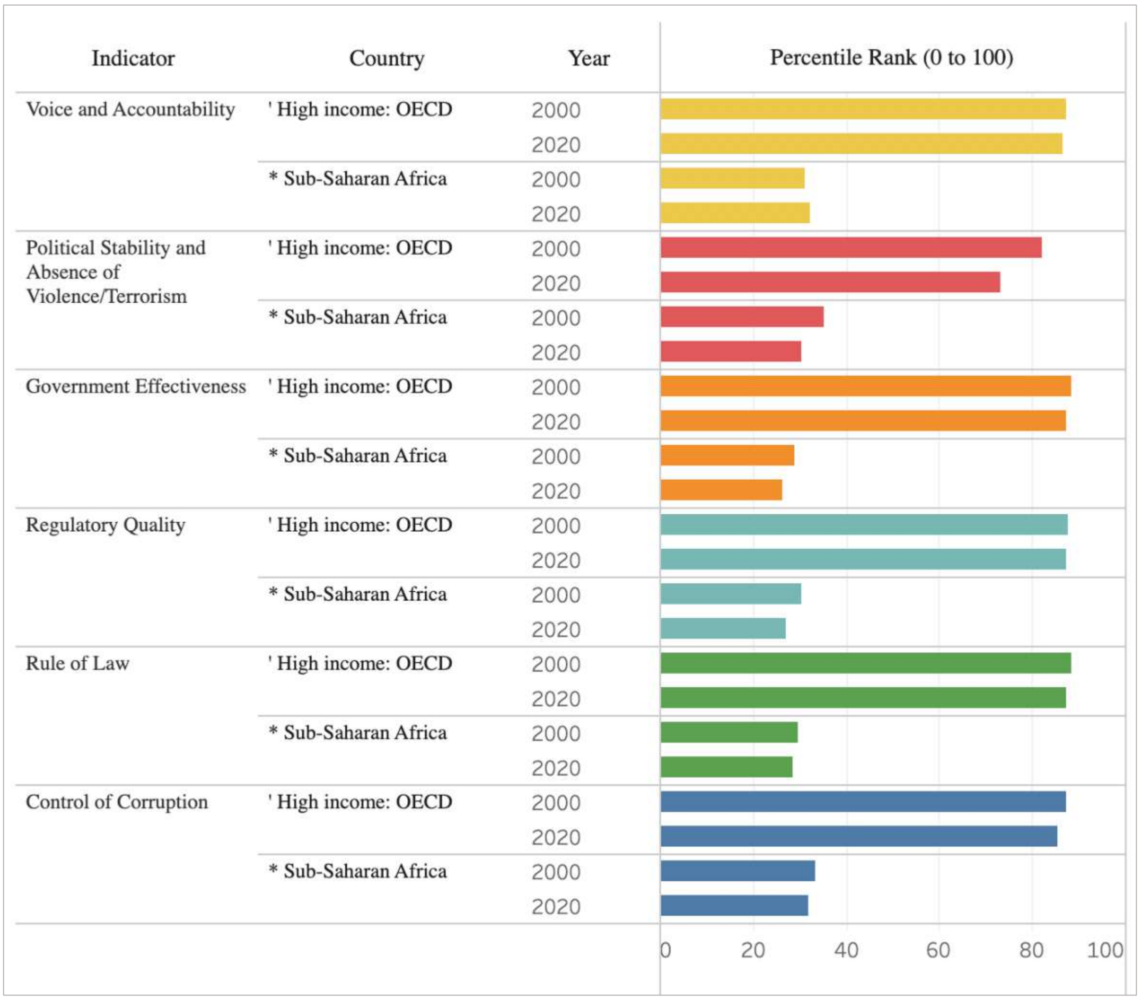

Figure 3: Worldwide Governance Indicators – Sub-Saharan Africa vs high-income OECD countries (World Bank, 2023d)

As the figure shows, there is a considerable distance to cover for sub-Saharan Africa to reach parity with the countries that host the majority of world's nuclear power reactors. Weak institutional quality, high levels of corruption, poor implementation of corruption control measures, weak rule of law and government effectiveness are only some of the issues that have debilitating effect on the development of nuclear EPR infrastructure and will require significant efforts to resolve on the way towards nuclear future. (Dumitru and Hayat, 2015)

Another important factor influencing political stability are *structural imbalances*, i.e., divergence between two or more development patterns. For example, when a transition to a democratic regime is not followed by a rise of GDP per capita levels, a structural imbalance is created which contributes to political instability. Consequently, democracies (or anocracies) with low GDP per capita are more vulnerable than any autocracies, such is the case for Nigeria. Another example is South Africa that suffers from a significant structural imbalance caused by a low life expectancy relative to the GDP per capita, result of the country's devastating HIV/AIDS pandemic. (Bello-Schünemann and Moyer, 2018, pp.18–20) Smart policies need to be implemented across sub-Saharan Africa to prevent further emergence of structural imbalances – a task that has proven to be immensely challenging for the region.

The final factor increasing the risk of political instability in sub-Saharan Africa are *horizontal inequalities*[9] – a phenomenon that is present and is expected to persist across the entirety of the region. Although present in all subregions, horizontal inequalities threatening political stability are more pronounced in Central and particularly in Western Africa. A comprehensive 2015 study done by the World Bank on four selected West African countries, including Ghana and Nigeria, showed that horizontal inequalities are severe and persistent, and that they pose a great threat to the political stability of the region – particularly since no serious efforts to remedy the inequalities have been detected in majority of the states at that time. (Langer and Stewart, 2015) They are reflected in the recurring conflicts that continue to destabilize the region and impede development which is why governments need to place a stronger emphasis on this issue, particularly in countries that are pursuing nuclear futures.

In summary, various factors persistently contributing to political instability in sub-Saharan Africa create an environment that is unfavorable for the development of a nuclear infrastructure and increases the risk of nuclear accidents occurring. With long-lasting political instability also comes deep-rooted public distrust in institutions and governments which has proven to be detrimental in nuclear and radiological emergency situations. There is a great potential in the region that stems from its youthful population and recent growth trends, however, this potential can only be exploited if cross-sectoral smart policies are implemented that can support all transformation paths *equally* and prevent

[9] Horizontal inequality can be assumed when different culturally defined sub-groups within a society are systematically (dis)advantaged, i.e., when certain groups hold disproportionately more or less economic, political, or social power than the others. (Stewart, 2004)

the emergence of structural imbalances. A tremendous coordination effort will be needed in the years to come, particularly in countries that have expressed nuclear power ambitions.

3.2.2. Poor economic performance

With the average GDP per capita in the region measured at $3.699 as compared to $45.087 in OECD countries or $16.752 for the world average in 2021, sub-Saharan Africa is not likely to reach SDG 1: No Poverty, by 2030. More importantly, the population suffering from multidimensional poverty[10] in 2022 was estimated at 49,5% with the additional 18,6% being at high risk. A devastating 27,9% of the total population is suffering from *severe* multidimensional poverty. (UNDP, 2023b; 2023a)

In addition to high percentage of population living in poverty, the population that is living just *slightly above* the poverty line has proven to be a significant challenge in recent years, as demonstrated during the Covid-19 pandemic. This group is not a target of most humanitarian assistance programs or social protection initiatives, yet they are at a high risk of falling under the poverty line as a result of even a minor shock. (UN DESA, 2022a, pp.102–112) Nuclear accident occurring in one such region would have much more devastating consequences that those seen in the past.

The region's adverse economic situation can be traced back to its colonial past and the subsequent decades of internal conflicts, unfavorable climatic conditions, poor governance coupled with weak institutions, resource scarcity, low export diversification and many others. Sub-Saharan rapidly growing population and the ever-increasing effects of climate change are expected to further aggravate the existing issues in the coming years. Significant investments across all sectors are necessary to reach the targets outlined by SDG 1, both by the international community and local governments. (FAO and IFAD, 2023, pp.1–31)

Extensive research in the field of disaster management has been done in the past couple of decades and it has been proven many times over that poverty is a key factor

[10] Multidimensional poverty reflects not only household economic deprivations but also deprivations in areas of health, education, and standard of living. (MPPN, 2023)

contributing to vulnerability, acting both as a driver of disaster risk as well as a direct consequence of it. Be it human-made emergencies such as nuclear ones, or those stemming from natural causes, populations suffering from multidimensional poverty are more likely to inhabit hazard-exposed areas. Additionally, they have very limited capacity to implement risk-reducing measures, be it due to the lack of education, poor health, or insufficient financial means. Lastly, as they are unlikely to have any social protection or insurance, people afflicted by multidimensional poverty have no choice but use their already diminished resources to cope with the consequences of the emergency which only aggravates their adverse living conditions. (UNDRR, 2021) Whereas this has only been a marginal issue for most nuclear countries in the world, sub-Saharan nuclear newcomers cannot treat it as such. The fact that the majority of the population in the region can be classified as vulnerable will require unprecedented efforts when devising national and regional nuclear emergency preparedness and response plans. The unique conditions in the region will have to be reflected in the nuclear emergency preparedness infrastructure, with special provisions put in place to acknowledge and protect the vulnerable population.

Lastly, it is important to note that none of the countries in sub-Saharan Africa currently have the financial resources to start a nuclear power program on their own. Ghana, Kenya, Nigeria and Uganda have all received offers from Rosatom in the past and are currently in negotiations, considering offers by different vendors from the US, Russia, Canada, China and South Korea. (Kumon, 2023; WNN, 2023b; 2023a) While these countries would finance the building and the operation of nuclear power plants, the costs for all the accompanying elements do not appear to be included in their offers. Nuclear emergency preparedness and response infrastructure is a crucial component that requires immense financial and human capital investments. It is highly unlikely that countries with low economic performance can shoulder this additional financial burden.

3.2.3. Human capital deficiencies

Rapidly growing population is one of the most prominent traits of the modern African continent with the annual population growth rate of 2,5% as opposed to a 0,8% global average in 2022. By 2050, the population of the sub-Saharan region is projected to almost double, contributing to more than a half of the anticipated global population increase. (UN DESA, 2022b, pp.3–5) Additionally, being at an early stage of demographic transition, sub-Saharan region is currently experiencing an equally rapid growth of working-age population. This can be seen as an opportunity to capitalize on the benefits of the demographic dividend[11] and accelerate economic growth. However, in order to seize this opportunity, an immense and carefully planned investment in *human capital* is necessary, with particular focus on ensuring universal health care and access to *quality education* for people of all ages while simultaneously creating productive and fair employment opportunities. (UN DESA, 2023, pp.17–34) When the increase in working-age population is not accompanied by such measures, high youth unemployment rates lead to political instability which is the case for many counties in the region at the moment.

Recent data shows that sub-Saharan Africa has the lowest performance in the world when it comes to all SDG 4 targets and indicators.[12] The rates of out-of-school children and adolescents are the highest out of all the world regions and significantly above the global average: 19,9% vs 9,0% for primary school age, 33,2% vs 13,9% for lower secondary school age, and devastating 47,8% vs 30,2% for upper secondary school age. Additionally, sub-Saharan Africa remains the only region where out-of-school population has been continuously on the rise: 78 million in 2009 vs 98 million in 2021. (UNESCO, 2022)

Statistical data on the *quality* of education also paints a bleak picture for sub-Saharan Africa. With regard to learning outcomes, even the top three performers in sub-Saharan Africa still score significantly lower than the weakest performers in Western Europe, as demonstrated in Figure 4. Research shows that educators in sub-Saharan Africa work in difficult conditions, receive inadequate training and struggle with motivation due to low wages. This is considered to be one of the major obstacles to improving the quality of education in the region. (Lauwerier and Akkari, 2015) As the education demand grows due to the rising young population, governments will need to prioritize investments in education, with the focus on improving its quality, along with the access.

[11] Demographic dividend can be defined as a window of opportunity for economic growth that opens up in a country when the proportion of its working-age population is higher than that of non-working-age population (UNFPA, 2023)
[12] Sustainable Development Goal 4: *"Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"* (United Nations, 2023c)

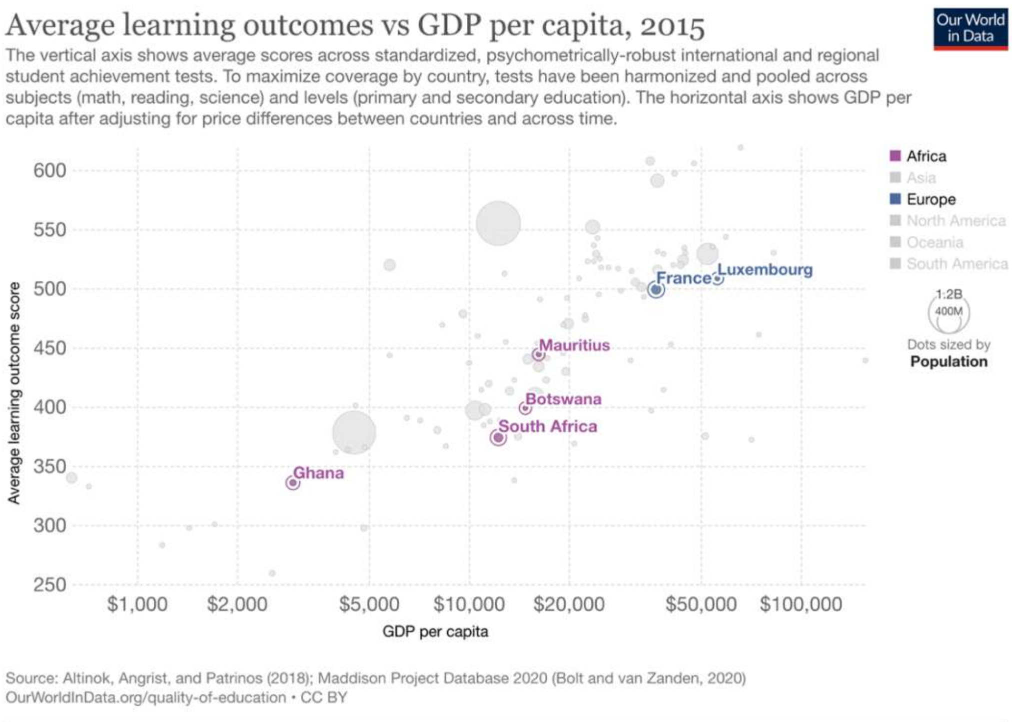

Figure 4: Average Learning Outcomes 2015, highest performers in sub-Saharan Africa vs lowest performers in Western Europe
(Ortiz-Ospina, 2018)

When it comes to participation and access to tertiary and adult education, sub-Saharan Africa is also significantly behind the rest of the world. (UNESCO, 2021, p.409) Unsurprisingly, these statistics are reflected in the *nuclear sector* as well. Although existing, Africa's nuclear science and technology sector is still relatively small and predominantly located in countries outside of sub-Saharan region. Additionally, with regard to nuclear education, there is still a lot of reliance on third parties such as the IAEA who has been offering assistance in form of trainings and educational events or Rosatom who has been offering scholarships and free education programs to students from the region. (Rosatom, 2020; IAEA, 2023a) When taking into account the variety of highly skilled professionals required to safely operate a nuclear power plant and maintain an efficient emergency preparedness and response network, educational and human capital statistics in the region pose a concern.

3.2.4. Weak health systems performance

Sub-Saharan Africa has always had a significantly larger disease burden than most other regions in the world. Its unique epidemiological situation can be almost entirely explained by its distinct climatic conditions and its slow pace of urbanization. In 2019, more than half of all deaths on the continent could be attributed to communicable diseases, the largest percentage of which were still the infectious and parasitic kind. In recent years, non-communicable diseases have been an added burden and have even overtaken infectious and parasitic diseases as the leading cause of productivity loss on the continent for the first time in history – a phenomenon referred to as epidemiological transition. This double burden places an enormous strain on transitioning health systems in sub-Saharan Africa. Urgent action is needed in form of continent-wide institutional reforms, modernization of curricula for health professionals, as well as complete re-thinking of the way resources are allocated in the health sector. However, for most of the region's low-income countries, the financial resources required for such an endeavor pose an insurmountable challenge. (WHO, 2019a)

A review of studies on the current state and performance of health systems in sub-Saharan Africa reveals a few key issues and focus points for going forward:

- Lacking numbers and maldistribution of healthcare professionals
- Absence of adequate administrative policies
- Lacking support infrastructure: social, economic, and technological
- Inadequate budgetary allocation to the health sector
- Unclear division of tasks and roles between physician and non-physician healthcare professionals
- Deficiencies in the education and training of healthcare professionals

Sources: (Greysen et al., 2011; Olapade-Olaopa, Sewankambo and Iputo, 2016; Olerribe et al., 2019; WHO, 2019b; 2022)

In context of nuclear and radiological emergency preparedness, one dimension of health systems performance is of particular interest – *resilience to disruptive shock events*. According to WHO findings in 2020, the general health systems performance in sub-Saharan Africa is 53,3/100, suggesting that health systems are operating at only 53,3% of what is feasible. The figure is even lower for resilience of systems to disruptive shock events – 51,5%. South Africa – home to the region's sole nuclear power station – scores significantly higher in resilience than all other countries, with 93,8/100. In comparison, nuclear newcomers Ghana, Kenya and Nigeria score only 40,2, 69,1, and 56 respectively. (WHO, 2020)

In other words, should a theoretical nuclear or radiological emergency occur *now*, health systems in newcomer countries would only be able to do 40,2% - 69,1% of what is feasible (and necessary) in this situation. Such an outcome is dangerously inadequate and further reiterates the urgency of health systems reform in the region. Current state of affairs in newcomer countries is in stark discord with their nuclear ambitions. In order to catch up, an immense coordinated effort needs to be undertaken, coupled with a significant increase in investments across all aforementioned sectors.

3.2.5. Basic infrastructure deficit

For the purpose of this thesis, *basic infrastructure* should be understood as physical systems that enable the functioning of an economy: aviation, railways, roadways, telecommunications, power and energy, water and waste management facilities etc. It is not to be confused with *soft infrastructure* – intangible system components such as institutions, regulations, policies, and human resources which enable the functioning of physical systems. This chapter will focus on deficiencies in basic infrastructure which inhibit economic growth across the region and pose a concern in context of nuclear emergency preparedness and response.

One way of trying to assess a government's ability to provide the most basic infrastructure and services to its people is looking at access to water, sanitation and hygiene within a country or a region. In 2022, only 31,35% of sub-Saharan population had access to safely managed drinking water, 24,35% had access to safely managed sanitation and merely 23,23% had access to basic hygiene facilities. To decrease the vulnerability in nuclear emergencies, national EPR plans should place higher emphasis on the provision of clean water, sanitation facilities, and hygiene education, seeing as they are crucial for decontamination, evacuation and sheltering efforts. Furthermore, efforts should be made to strengthen the overall resilience of these communities to ensure they are better equipped to cope with potential emergencies.

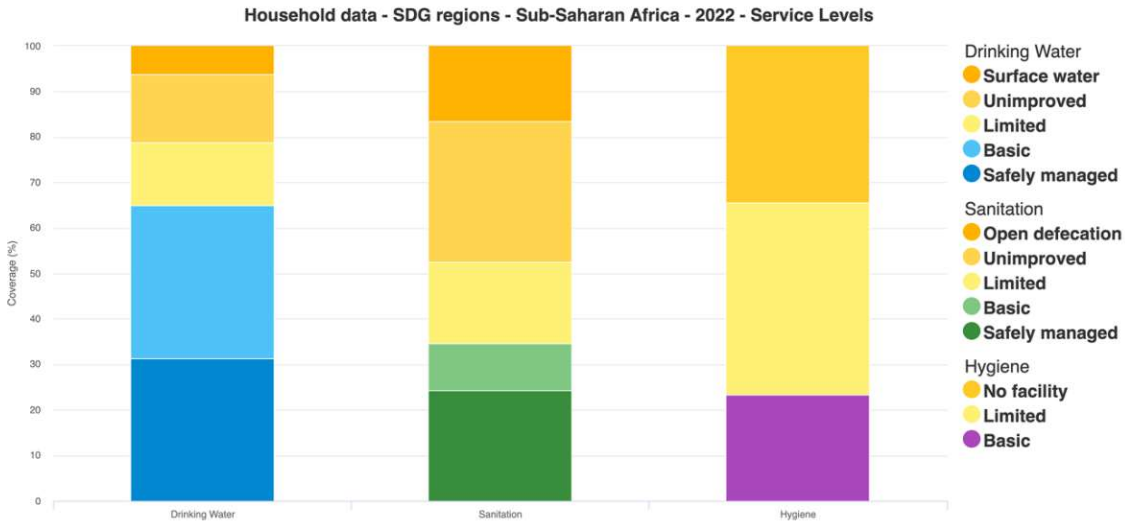

Figure 5: Water, sanitation, hygiene access in sub-Saharan Africa, 2022 (WHO and UNICEF, 2023)

Statistical data on *telecommunication* and *transportation* infrastructure in sub-Saharan Africa – two additional elements crucial for nuclear EPR – paints a very similar picture: limited access, insufficient coverage, inadequate or outdated physical components as well as disproportionately high usage prices in comparison to the rest of the world. (African Development Bank, 2018) Global data collected by the International Telecommunication Union shows that sub-Saharan performs significantly lower than the rest of the world in nearly all aspects of information and communication infrastructure. Analysis of data on roads, railways, ports and air traffic also shows significant infrastructural deficits, most prominently an underdeveloped network, poor maintenance of and low performance of existing elements. (Gwilliam, 2011; ITU, 2023) During a nuclear emergency, such deficiencies can impede emergency response, jeopardize public safety, and complicate efforts to mitigate the impact and the consequences of the emergency. As a result, investing in robust and resilient transportation and communication infrastructure is crucial for effective nuclear emergency preparedness and response.

As evidenced in countless cases of naturally occurring disasters in the past, societal dependency on basic infrastructure becomes most evident in the wake of service disruptions. This is why robust emergency preparedness and response systems are of such importance. The establishment of nuclear EPR infrastructure requires an already solid foundation - it cannot be built upon an inherently flawed or deficient framework. It is imperative for nuclear newcomer countries in sub-Saharan Africa to undertake substantial enhancements in their most fundamental infrastructure sectors such as drinking and wastewater, telecommunications and transportation. These improvements will lay the groundwork for facilitating the establishment of robust nuclear emergency preparedness and response systems.

3.3. Prevalence of identified challenges in nuclear frontrunner countries in sub-Saharan Africa

The five region-specific challenges identified in previous chapters are not equally present in all countries in sub-Saharan Africa, manifesting with varying degrees of intensity. The following table provides an overview of how prevalent and acute the five challenges are in each of the region's nuclear frontrunner countries. The prevalence/intensity is assessed on a scale of Low, Moderate, High and Very High, and is based on the analysis of most recent available data from international organizations. The scale should be understood as follows: 1) low = the prevalence indicates the identified issue will *not* affect nuclear EPR capacity, 2) moderate = the prevalence indicated the identified issue could *potentially* affect nuclear EPR capacity, 3) high = the prevalence indicated the identified issue will *very likely* affect nuclear EPR capacity, 4) very high = the prevalence indicates the identified issue will *most definitely* affect nuclear EPR capacity.

Table 2: Prevalence of identified challenges in nuclear frontrunner countries in sub-Saharan Africa

Challenge	Political instability	Low economic performance	Human capital deficiencies	Weak health systems performance	Basic infrastructure deficit
Ghana	Moderate	High	High	Moderate	High
Kenya	High	High	High	Moderate	High
Nigeria	Very High	High	Very High	High	High
Sudan	Very High	Very High	Very High	High	Very High
Niger	Very High	Very High	Very High	High	High
Rwanda	Low	High	High	Moderate	High
Uganda	High	Very High	Very High	Moderate	High
Zambia	Moderate	High	High	Moderate	High
South Africa	High	Low	Moderate	Low	Moderate

With the exception of Rwanda which showcases a relatively high level of political stability and South Africa with solid economic and health systems performance, each of the five identified challenges is at least moderately prevalent in all of the nuclear frontrunners in sub-Saharan Africa, with high and very high prevalence being the most common result. However, each country has a unique profile consisting of a different set of challenges with differing degrees of intensity. Even though countries like Rwanda, Ghana and Nigeria have made significant strides in recent years when it comes to education of nuclear professionals, the overall national educational statistics remain very low and the countries' reliance on third parties remains very high, particularly when compared with experienced nuclear countries. Additionally, although Rwanda has showcased admirable economic growth and infrastructural development in the past decade, the GDP per capita remains very low while high inflation and unemployment rates persist. Similarly, access to safely managed water and sanitation facilities remains very low while transportation and communication networks remain underdeveloped. In other words, even though progress is evident, the prevalence of identified challenges is still very high, particularly when compared with other regions or other countries hosting nuclear power plants.

Although this table only provides an at-a-glance overview of national differences in how the challenges are experienced, it is abundantly clear that none of the countries can provide the environment which is conducive for the development of nuclear EPR infrastructure, seeing as the very foundation for it is missing. Even South Africa, which has been home to two commercial nuclear reactors for nearly four decades has since developed moderate to high issues in several of the categories and would need to revise their nuclear EPR arrangements in order to adjust to the new unfavorable environment, particularly in light of their firm intention to upgrade their nuclear capacity by extending the lifetime of existing facilities and building new ones.

Nevertheless, a closer look at all the nuclear EPR requirements is needed, as well as a more comprehensive assessment of nuclear EPR capabilities in specific countries, both of which will be addressed in the following chapters.

4. Nuclear EPR in sub-Saharan Africa: key requirements outlined by the IAEA

This chapter will introduce the most essential requirements of nuclear emergency preparedness and response identified by the IAEA, starting from basic ideas down to the necessary infrastructure and operational concepts. In addition to select general, functional and infrastructural IAEA requirements presented in this chapter, additional requirements will be introduced in chapter 5, based on the key findings on region-specific challenges from chapter 3 of the thesis. Furthermore, these newly identified requirements will be combined with those outlined by the IAEA in order to build a weighed assessment model for nuclear EPR infrastructure that is suited for sub-Saharan Africa and addresses all the region-specific challenges.

4.1. Terminology and basic concepts

To gain a solid understanding of the subject of nuclear and radiological emergency preparedness, certain terminology and basic concepts must first be examined. When applied in the later course of the thesis, all concepts, terms, and their respective definitions introduced in the following sub-chapters shall be interpreted exclusively as described herein, with close attention to field-specific connotations, and shall not be confused with the definitions of the same concepts for purposes other than emergency preparedness.

Types of emergencies

In general, a nuclear or radiological emergency can be characterized as any situation "*in which there is, or is perceived to be, a hazard due to: (i) the energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction; or (ii) radiation exposure.*" (IAEA, 2020) However, for the purpose of emergency preparedness, a distinction can be made between the two:

- *Nuclear* emergencies pertain to threat categories I, II and III and can occur at nuclear reactors, nuclear storage facilities, large irradiation facilities, fuel cycle facilities, industrial or research and medical facilities
- *Radiological* emergencies pertain to threat category IV and can occur anywhere since they result from transport emergencies, abandoned, lost, stolen or found dangerous sources or their misuse, public exposure from unknown origins, malicious acts etc.

Source: (IAEA, 2007, pp.3–4)

Threat categories[13]

To facilitate the planning of arrangements for emergency preparedness, practices and activities for which emergency response (ER) may be required are grouped in five threat categories with *decreasing* levels of nuclear and radiation related threat and equivalent requirements for emergency preparedness and response. However, seeing as nuclear renaissance in the region refers to national plans to build and operate *nuclear power plants*, only threat categories I, II and V will be considered going forward.

Table 3: Categories of nuclear and radiation related threats

Category	Description	Example
I	Facilities at which a release of radioactive material or external exposure[14] originating *on the site* are conceivable and could lead to the occurrence of severe **deterministic** health effects *off the site* calling for urgent response action under any circumstances in conformity with standard international practices[15], including types of facilities at which such events have taken place in the past	Nuclear power plants
II	Facilities at which a release of radioactive material or external exposure originating *on the site* are conceivable and could lead to the occurrence of **stochastic** health effects *off-site* calling for urgent protective action in conformity with standard international practices, including types of facilities at which such events have taken place in the past	Research reactors
V	**Activities** not typically linked to sources of ionizing radiation, but which yield goods likely to	Agricultural fields contaminated by

[13] Not to be confused with INES scale, which considers safety significance and *impact* of nuclear events

[14] External exposure occurs when irradiation is emitted by sources *outside* the body vs. *inside* the body in case of internal exposure (IAEA, 2003, p.256)

[15] For greater insight into international standards, please refer to (IAEA, 2015d, pp.62–73)

	be exposed to contamination *as a result* of release of radioactive material at facilities of threat category I or II, taking into account the possibility of transboundary contamination, calling for prompt restrictions on goods in conformity with standard international practices.	releases from facilities in threat categories I and II

Source: Adapted from (IAEA, 2003, pp.5–6)

Exposure pathways

Exposure pathways represent the routes by which individuals or groups of people can become exposed to radiation or radionuclides: external exposure, ingestion, inhalation and contamination. (IAEA, 2007, pp.8–9; 2019, pp.40, 104) Understanding and predicting them is crucial for the purposes of emergency preparedness, particularly in complex emergencies or for activities falling under threat categories I and II where more than one exposure pathway could come into play.

Health effects

As one of the principal objectives of emergency preparedness is to prevent, protect from, mitigate, and minimize negative effects radiation could have on the health of the human population, it is important to make a distinction between two types of health effects radiation can bring about, each warranting differing stringency of response measures.

Deterministic effect is defined as a radiation-induced health effect *"for which generally a threshold level of dose exists, below which there is no effect and above which the severity of the effect increases with the dose received."* (IAEA, 2007, p.4) If such an effect results in death, is life-endangering or leads to a lasting injury that diminishes one's quality of living, it is understood as a *severe deterministic effect*. (IAEA, 2019, p.107)

Stochastic effect is defined as: *"health effect, the probability of occurrence of which is greater for a higher radiation dose and the severity of which (if it occurs) is independent of dose"* (IAEA, 2007, p.135) In other words, it is presumed that no threshold level exists below which no effect could occur – even extremely low doses could lead to lasting and indelible effects, another difficulty being that their occurrence is normally delayed – up to many years after the exposure. Cancers and hereditary disorders are the two main examples of stochastic effects. (Government of Japan, 2013)

Areas and zones

For the purposes of emergency preparedness and response planning, it is important to distinguish between different emergency areas and their sub-classes (herein referred to as zones) given that differing requirements are prescribed for each generic area.

The **on-site** area is defined as a *"geographical area that contains an authorized facility, authorized activity or source, and within which the management of the authorized facility or authorized activity or first responders may directly initiate emergency response actions."* (IAEA, 2019, p.22) The on-site area is easily distinguished for the facilities falling under threat categories I and II as the site boundary is very prominent – an easily detectable security perimeter fence or another distinctive property marker. The **off-site** area can be defined as a geographical area beyond the site boundary, i.e., beyond the area controlled by the operator or first responders. Off-site areas need to be defined for emergencies at facilities falling under the threat categories I and II and are further divided into precautionary action zone (PAZ) and urgent protective action planning zone (UPZ), as shown in Figure 6.

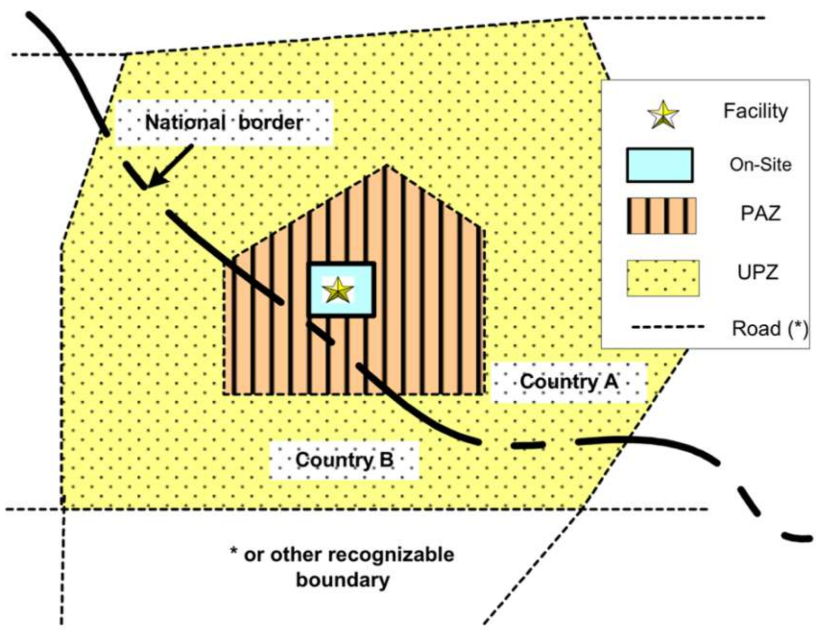

Figure 6: Emergency zones
(IAEA, 2003, p.10)

4.2. General requirements

Bearing in mind the terminology and the concepts introduced in chapter 4.1., the following chapter will introduce the most basic requirements for emergency planning and preparedness, herein referred to as general requirements. IAEA GSR Part 7 provides the most up-to-date international standards on all matters related to nuclear emergency preparedness and response and will serve as the main reference point for all the elements introduced in the following sub-chapters.

4.2.1. Basic responsibilities

The most basic prerequisite for efficient emergency preparedness and response planning is the adoption of legislation which clearly allocates responsibilities in a nuclear emergency at all levels.

Operator level

Operator can be defined as a person, a group of persons or an organization authorized to directly exert control over a facility containing or an activity involving a radioactive source and therefore directly responsible for safety during suchlike activities. (IAEA, 2022b, pp.144–145) The responsibilities of an operator differ depending on the threat category and are summarized in the following table.

Table 4: Responsibilities of an operator in a nuclear emergency

Threat categories I and II	Threat category V
▪ Prompt detection and identification of an emergency or a hazard as well as the classification of the emergency (where appropriate) ▪ Immediate mitigatory action ▪ Measures to protect persons within the area under operator's control ▪ Establishment and continuous maintenance of communication with the off-site officials ▪ Attainment of off-site support	▪ Measures to assure prompt response upon receiving official instructions on protective action in regard to food chain and drinking water supply ▪ Supervision and management of potentially contaminated water and foodstuffs

▪ Recommendation of appropriate protective action to off-site officials as well as technical support ▪ Assistance in efforts to keep the general public well informed	

Sources: Adapted from (IAEA, 2007; 2015d)

Off-site level

Off-site officials can be defined as individuals and organizations carrying out off-site response actions in a nuclear emergency. The off-site level should consist of: 1) local officials, i.e. the government and its bodies in charge of assisting the operator and protecting the general public, 2) medical practitioners whose responsibility is to identify radiation-induced injuries and take further measures in accordance with international standards, 3) national and regional officers, i.e. government and non-governmental organizations in charge of emergency planning and response whose responsibility is to provide technical support to local officials and to implement nonurgent protective actions. (IAEA, 2003, p.10)

Table 5: Responsibilities of off-site officials in a nuclear emergency

Threat categories I and II	**Threat category V**
▪ Prompt implementation of urgent protective actions in all emergency zones ▪ Environmental monitoring and assessment ▪ Introduction of measures to curb the consumption of contaminated water and foodstuffs ▪ Provision of emergency services to the operator upon request ▪ Provision of immediate medical treatment of persons exposed to radiation as well as arrangements for long-term medical care ▪ Continuous transmission of information and instructions to the media and the general population in simple language	▪ Issuance of instructions on the protection of the food chain and the drinking water supply in conformity with the most recent international standards ▪ Issuance of instructions on the supervision and management of potentially contaminated water, foodstuffs, and other products in conformity with the most recent international standards

▪ Response to inadequate public reactions ▪ Communication with the IAEA	

Sources: Adapted from (IAEA, 2007; 2015d)

International level

The international domain in nuclear emergencies comprises of (international) organizations which provide global assistance as prescribed and illustrated in the 2017 'Joint Radiation Emergency Management Plan of the International Organizations' which was collectively sponsored by twenty different international organizations, including the IAEA, the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO) and the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). (IAEA, 2017)

The IAEA plays a central role in the facilitation of information exchange, prompt decision-making and assistance provision in nuclear emergencies. This authority has been delegated to the IAEA since 1986, via two crucial legal instruments – the "Convention on Early Notification of a Nuclear Accident" often referred to as the 'Notification Convention' and the "Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency", also known as the 'Assistance Convention'. Four vital international organizations are also party to the conventions, namely the European Atomic Energy Community (Euratom), the World Meteorological Organization (WMO), the WHO, and the FAO, in addition to 128 countries in case of the Notification Convention and 123 countries in case of the Assistance Convention. (IAEA, 2023c; 2023b)

National coordinating authority.

Each state embarking on a nuclear journey should select an existing government body or a governmental organization and grant it authority to serve as a national coordination mechanism for activities such as hazard assessment and review within the national borders and ensuring that the operators and all response organizations have clearly appointed and well comprehended functions and responsibilities. (IAEA, 2016, pp.10–12) The national coordinating authority should have following responsibilities:

- Arrange for a regular performance of hazard assessment to identify any new activities or situations that may require emergency response, including a continuous exchange of information with neighboring countries.
- Examine which functions each organization intends to take on in an emergency, whether they actually fall under their jurisdiction and whether the resources at the organization's disposal are sufficient to perform the intended functions. The results of this examination shall be evaluated at the national, regional and local level to detect any existing gaps and inconsistencies as well as overlays and conflicts in the arrangements of different organizations, and to resolve them.
- Ensure that there is a common agreement among all organizations participating in emergency response in regard to their officially assigned responsibilities.
- Facilitate the development of the national radiation[16] emergency plan as a part of the larger, all-hazards emergency plan, as shown in Figure 7.
- Coordinate efforts to ensure that emergency preparedness and response requirements are implemented in the praxis as prescribed by national legislation and in conformity with international standards
- Should an emergency happen, coordinate the follow-up analysis of the emergency situation, as well as the examination of the emergency response
- Coordinate efforts to inform and educate the general public as a vital part of nuclear emergency preparedness

Sources: (IAEA, 2007, pp.20–22; 2015d, pp.9–10)

4.2.2. All-hazards approach

Nuclear emergencies rarely occur in isolation. In most cases, they are either caused or accompanied by other types of hazards such as natural disasters, technological accidents or criminal activities. Consequently, the response to nuclear emergencies often requires close cooperation of various types of response organizations, depending on the situation. This understanding needs to be taken into account early on in the preparedness stage, hence the integrated planning concept, commonly referred to as 'all-hazards approach'. (WHO, 2023)

[16] 'radiation emergency' should be understood as a nuclear or radiological emergency in this context

The IAEA has recognized the importance of the integrated planning concept and has included it in its Safety Standards: *"the emergency management system shall be integrated, to the extent practicable, into an all-hazards emergency management system"* (IAEA, 2015d, p.8) In other words, nuclear emergency preparedness and response planning should be conducted in full cooperation with national, regional and local response organizations managing conventional emergencies such as natural or technological disasters, terrorist acts or other forms of criminal activity.

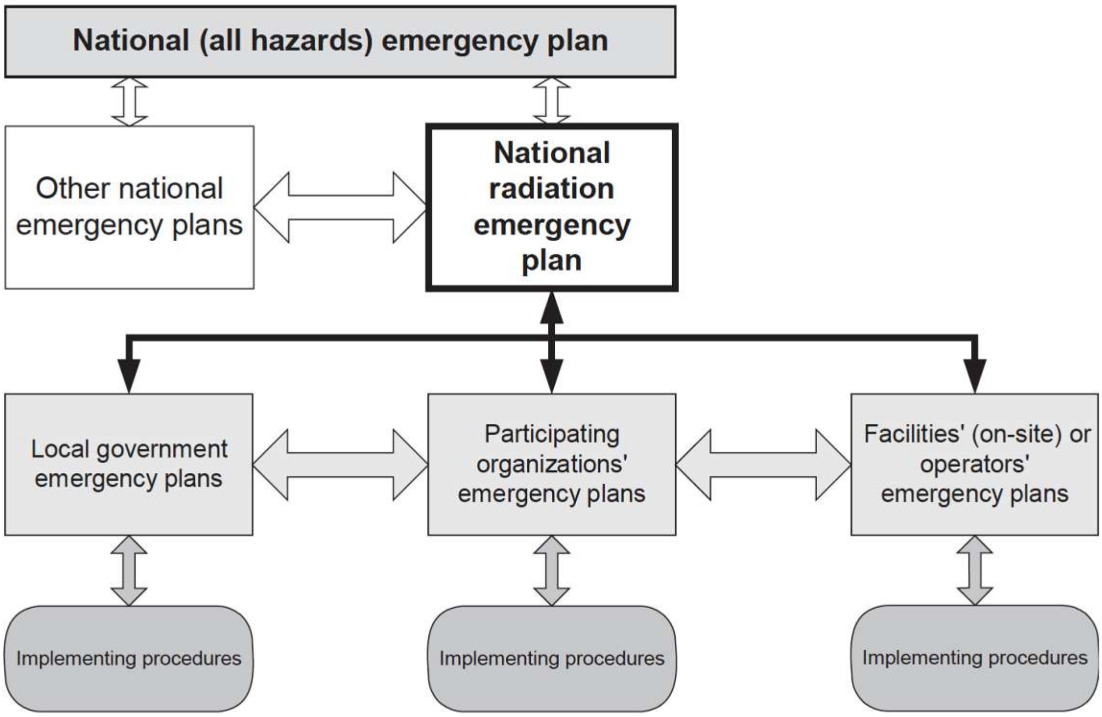

Figure 7: All-hazards emergency management system, integrated planning concept (IAEA, 2007, p.23)

4.2.3. Threat assessment

As previously discussed in chapter 4.2.1., one of the main responsibilities of the national coordinating authority is to ensure regular execution of threat assessments within the national borders and a periodical review of their results. National coordinating authority should cooperate with operators and other relevant organizations in examining the entire area of the country in order to:

1) identify all facilities, activities, sources, on- and offsite areas and locations that could require urgent protective action aimed at preventing severe deterministic or

stochastic effects, long-term protective measures, agricultural measures, measures to prevent ingestion or measures to protect response personnel in case of a nuclear emergency

2) assess threats arising from said facilities, activities, sources, on- and offsite areas and locations in order to establish as which threat category they should be classified
3) based on the results of threat assessment, develop *protection strategies* for taking protective and other response action during an emergency

Source: (IAEA, 2015d, pp.12–16)

Ultimately, the national coordinating body should facilitate the integration of all gathered results, their documentation and their inclusion in the national radiation emergency plan. The final results should be presented in a form of a list and a map showing the locations of all identified facilities and activities as well as their assigned threat categories. (IAEA, 2007, pp.24–26) Arrangements need to be made for the threat assessment to also include in the list hazards that are not radiation related but may endanger people both on-site and off-site and therefore hinder emergency response. (IAEA, 2015d, p.16)

4.3. Functional requirements

Chapter 4.2.1. introduced basic responsibilities and functions of parties involved in nuclear emergency preparedness and response at all levels. The following chapters will look closely into said functions and discuss the arrangements that need to be put in place for their effective performance.

4.3.1. Identify, notify, activate

Experience from past nuclear and radiological emergencies has shown that facility and source operators have often failed to recognize and understand the severity of the situation following incidents involving an unplanned release of radioactive material, despite the presence of clear warning signs. Any delay in the identification of the emergency situation and the consequent selection and implementation of appropriate response actions can lead to catastrophic consequences, including loss of human life or lasting injuries due to severe deterministic or stochastic effects of radiation, environmental destruction and many non-radiological consequences such as psychological trauma, and societal or economic repercussions. Therefore, the arrangements need to be put in place that allow for prompt and accurate identification and notification of the emergency as well as swift activation and coordination of both on-site and off-site response actions. (IAEA, 2007, pp.29–30)

As previously shown in Table 4, 'prompt detection and identification of an emergency or a hazard as well as the classification of the emergency' is one of operators' key responsibilities. Additionally, it has been shown that the determination of appropriate levels of response as well as the activation of response actions also falls under the operators' jurisdiction. In order to understand this process, two new concepts need to be introduced: 1) emergency action level (EAL) and 2) emergency class.

Emergency action level, commonly abbreviated as EAL, is defined as a "*specific, predetermined criterion for observable conditions used to detect, recognize and determine the emergency class*". (IAEA, 2019) EALs often contain symptomatic thresholds that allow for swift and nearly effortless determination of the appropriate emergency class using only information that is readily available and easily collected during the initial stages of the emergency. A common example of an emergency action level would be a reading from an instrument or a clearly discernable event such as flooding or a fire. (IAEA, 2007, p.30)

Emergency class can be understood as a "*set of conditions that warrant a similar immediate emergency response*" (IAEA, 2019, p.75) and is primarily used for the purpose of conveying the required response level to the general public and the relevant response organizations. In order to ensure prompt selection and activation of adequate response measures, each emergency class is coupled with a corresponding predefined set of initial actions[17] for the response organizations to carry out. This way, correct classification of the emergency automatically leads to the launching of appropriate response actions. (IAEA, 2022b, pp.69–70) IAEA defines five different emergency classes, four of which are possible at facilities in threat category I and II, with the descending severity of emergency: general emergency, site area emergency, facility emergency and alert[18].

[17] Different types of emergency response actions will be discussed in more detail in chapter 4.3.2.
[18] For a detailed characterization of emergency classes, IAEA Safety Glossary can be consulted

Additionally, a minimum of one **off-site notification point** need to be set up to serve as posts that are continuously available to receive and respond to any emergency notifications and requests for assistance and are able to establish instantaneous communication with response organizations under any circumstances and at all times. Arrangements need to be made for notification points to be able to instigate predetermined and coordinated emergency response actions off-site or to be capable of establishing *instantaneous* communication with the body which has the authority to determine and instigate protective actions and other response actions off-site. (IAEA, 2003, pp.50–51)

In summary, arrangements shall be put in place to enable, in case of a nuclear emergency, a swift and efficient process comprising of the following sequence of actions: 1) promptly identify and classify the emergency; 2) announce the emergency class and instigate a pre-coordinated response on the site; 3) inform the allocated notification point (or points) and make enough information available for an effective response off the site; 4) coordinate a pre-determined offsite response, adjusted as needed, according to the protection strategy. (IAEA, 2015d, p.24)

4.3.2. Urgent protective actions

All emergency response actions can be divided into two categories – protective actions and other response actions – and can be understood in the following manner:

- Protective action is defined as an action undertaken with the objective of evading or minimizing doses that would be received due to radiation exposure if no action was undertaken. Types of protective actions are: mitigatory action, early protective action, urgent protective action, precautionary urgent protective action.
- Other response action is any ER action that does not fall under the category of protective action. Common example for the provision of other response actions would be a medical treatment, psychological counseling or any other action aimed at mitigating non-radiological consequences of a nuclear emergency.

Source: (IAEA, 2022b, pp.72, 161–162)

Now that a distinction has been made, a closer look needs to be taken at *urgent protective actions*. They are prominently thematized in nuclear EPR literature due to their nature –

they need to be executed with utmost precision and swiftness which requires a lot of meticulous planning, great expertise and continuous training. Arrangements need to be made for countries to be able to undertake the following vital urgent protective actions:

- Isolation of the radioactive source as well as the area of contamination
- Evacuation and provision of emergency shelter to the affected population
- Protection of the respiratory tract, skin and eyes
- Measures to prevent accidental ingestion
- Stable iodine prophylaxis
- Decontamination of persons and equipment
- Protection of the drinking water supply and the food chain as well as management of contaminated water and food
- Medical response management
- Measures to protect international trade

Source: (IAEA, 2007, pp.95–103)

Although international standards exist that prescribe when measures such as evacuation, relocation or food restrictions are warranted, they are expressed as quantities that cannot be measured directly at the facility or its surrounding which is why arrangements need to be made by states to evaluate environmental monitoring results as quickly as possible. This assessment should serve as a basis for deciding which urgent protective actions are needed and *if* ones that are already being implemented need to be adjusted. (IAEA, 2003, pp.59–63) At this stage, utilization of operational intervention levels, commonly abbreviated as OILs, is of particular significance. An OIL is defined as a *"set level of a measurable quantity that corresponds to a generic criterion"*. (IAEA, 2019, p.126) OILs are a crucial part of any nuclear emergency planning and need to be established using realistic assumptions, long before the operational start of the facilities where nuclear accidents might potentially happen. These predetermined default OILs shall then be used to determine whether and when intervention is necessary during an emergency.

For emergencies at facilities in threat categories I, and II, where it is reasonable to assume that urgent protective action may be warranted *off-site*, the best way to ensure a timely and adequate implementation of the measures is to act without delay, immediately upon detection of abnormal or dangerous conditions. Waiting for a release of radioactive material to happen or awaiting the results of environmental monitoring can be detrimental in emergencies at facilities in threat category I where time is of essence. Decision making in the aftermath of the Chernobyl accident is a fitting example. After the accident occurred, it has taken the authorities several hours or even days to reach certain decisions and to implement urgent protective actions to protect the public. For example, many children developed thyroid cancer after receiving high doses to the thyroid by consuming dairy products from cows that were fed contaminated grass in the immediate aftermath of the accident. The relevant authorities imposed restrictions on the consumption of contaminated foodstuffs only several days after the accident – a delay that proved to be detrimental to the public health. (The Chernobyl Forum, 2005, p.13) Analyses of past accidents have also shown that even when the implementation of protective actions had been extensively debated and had taken a long time, oftentimes inadequate protective actions had been chosen since the arrangements for prompt decision-making did not exist prior to the emergency. (IAEA, 2012b, pp.20–21)

4.3.3. Communication with the public

During a nuclear emergency, it is of utmost importance to continuously keep the public informed. It is a duty of every government to assign responsibilities, establish institutions and procedures to *"provide the public who are affected or are potentially affected by a nuclear or radiological emergency with information that is necessary for their protection, to warn them promptly and to instruct them on actions to be taken."* (IAEA, 2015d, p.33) This task, however, comes with its own set of challenges, most notably the fact that the majority of general population lacks basic understanding of nuclear topics and the fact that emergency situations usually result in surges of panic among the affected and the potentially affected population.

Managing public fears during an emergency and making sure that the public remains calm and capable of receiving and following safety instructions is the first priority of individuals and organizations responsible for emergency communication. Mass panic is frequently regarded as a *natural* response to physical danger; however, research suggests that the provision of mutual aid is, in fact, more common and that humans display a tendency to seek the proximity of known persons and locations rather than to flee. (Mawson, 2005) Past events have shown that the onset of mass panic is usually triggered by the following factors:

- Confusing and inconsistent information received by the official sources, media, and other members of the public
- Uncoordinated delivery of public information by the official sources
- Usage of complex scientific language that is too difficult to understand for an average member of the general population
- Distrust in public institutions and officials
- Lack of pre-existing awareness of potential risks[19]

Source: (IAEA, 2007, pp.36–37)

Extensive preparation and meticulous planning are needed to combat said challenges and to ensure that each member of general public is given clear and timely information on the safety of the situation and how to protect themselves, their families, and their interests. Given that a number of organizations are involved in emergency response, there must be a clear delegation of responsibilities – each organization must have one *designated individual* acting as a news media liaison officer during the emergency. Provision of public information by different official sources – local and national authorities, the operator – must also be coordinated to ensure consistency and uniformity. Establishment of a public information center as a coordinating body and a sole source of information is strongly recommended. Additionally, all warnings, descriptions of risks, instructions as well as the questions posed by the public must be answered in a *plain and understandable language*. This requires extensive preparation given that nuclear emergencies are not a common occurrence, and the officials are thus not experienced in preparing such communication materials. Ultimately, provisions need to be in place to quickly identify and correct inaccurate, misleading, and harmful information during an emergency. This aspect is particularly important in situations where the incorrect information is originating from a source that is regarded as trustworthy by the general population and when such information may result in actions being taken that are beyond or conflicting with those recommended by the authorities. A good example would be that of medical practitioners who, despite being professionals in their own field, may have misapprehensions of the

[19] In other words, members of the public who have been unaware of the possibility of a nuclear emergency in their surrounding are more likely to succumb to irrational or fear-induced behaviors

radiation-associated risks and the ways to minimize them. (IAEA, 2003, pp.79–80; 2007, pp.36–37)

4.3.4. Medical response

The most basic requirement prescribed by the IAEA is for governments to make arrangements for all medical staff, including general practitioners and emergency medical personnel, *"to be made aware of the clinical symptoms of radiation exposure, and of the appropriate notification procedures and other emergency response actions to be taken if a nuclear or radiological emergency arises or is suspected".* (IAEA, 2015d, p.37)

Past experiences have demonstrated that many local hospitals and medical staff do not have sufficient knowledge and expertise to treat overexposed and contaminated patients adequately. To this day, only a small number of medical facilities in the world have considerable hands-on experience with the diagnosis and handling of radiation-induced injuries. Given the state of things, governments must make arrangements at the national level for exposed or contaminated persons to receive adequate treatment. A set of guidelines for response to all possible emergencies, including nuclear emergencies, must be devised, and shared with local medical centers. Since not every local hospital can specialize in the detection and treatment of radiation-induced injuries, provisions must be put in place to ensure patients can receive *initial* treatment wherever they may find themselves. Additionally, arrangements need to be made, both on a national and an international level, to, upon request, provide counsel and share expertise with local medical centers in an efficient and timely manner. There have been cases in the past where patients with radiation-induced injuries have received adequate treatment in local hospitals that lacked the expertise but were able to receive guidance from international specialists. Such assistance can be requested through WHO or the IAEA[20]. (IAEA, 2003, pp.75–78; 2007, p.39)

States must ensure that medical centers in the proximity of facilities in threat categories I and II have received sufficient training and are at an adequate level of preparedness to respond to all potential emergencies. Comprehensive analysis must be carried out to

[20] "Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency" requires all its parties to submit a list to the IAEA of, among other things, their available experts who can be consulted and provide assistance to other states in case of a nuclear emergency. (IAEA, 2023b)

determine individual capacities of medical centers in question. If it is established that they are not sufficient to be able to cope with the influx of patients under the worst-case scenario, arrangements must be made for emergency medical transport to other hospitals. For any number of potential patients, locations at which they are to receive initial medical treatment must be *predesignated*. (IAEA, 2015d, p.38)

Ultimately, it must be reiterated that medical response to nuclear emergencies does not end with the initial response. For the cases where individuals may have received doses that put them at a high risk of developing stochastic health effects, it is necessary for the governments to make arrangements to identify, track, monitor, and provide *long-term* health treatment for such individuals. (IAEA, 2003, pp.77–78)

4.3.5. Agricultural and countermeasures against ingestion, long-term protective actions

Ingestion of contaminated water and foodstuffs is a very common radiation exposure pathway. This is why it is essential that arrangements be made to enable prompt decision-making in regard to agricultural countermeasures and measures to prevent ingestion of contaminated water and agricultural products during and after a nuclear emergency. Some measures need to be implemented promptly to be effective whereas others do not require immediate action.

All areas inside the predetermined *ingestion and commodities planning distance* are, following a significant release of radioactive material, subject to urgent protective measures to prevent and minimize contamination and restrict the use all non-essential locally grown products, forest products, dairy products and eggs from grazing animals, drinking water or any other potentially contaminated commodities. The arrangements shall be made to:

- Provide advice and instructions to local authorities and the affected population
- If possible, prevent or minimize contamination of commodities, the food chain and drinking water supply
- Limit ingestion and use of contaminated or potentially contaminated products and commodities
- Monitor the areas and perform sampling and subsequent analysis to determine contamination levels

- Facilitate the enforcement of restrictions

Source: (IAEA, 2015d, pp.41–42)

Additionally, for areas and activities in threat category V, arrangements should be made for long-term protective actions such as relocation of population inhabiting affected areas, medical follow-up, long-term health monitoring, decontamination, and other remedial actions[21], measures regarding international trade, etc. Even though time sensitivity is much lower for such measures, they should still be devised during the emergency planning phase and implemented without any unnecessary delay. (IAEA, 2007, p.41) Ultimately, since threat category V often involves transboundary contamination, arrangements must be put in place to allow for swift communication and coordination between the affected states during the initial stages of the emergency and to enable effective long-term cooperation in the post-emergency stage. (IAEA, 2015d, pp.41–43)

4.3.6. Mitigation of non-radiological consequences

Non-radiological consequences in nuclear emergency response planning are defined as "*adverse psychological, societal or economic consequences of a nuclear or radiological emergency or of an emergency response affecting human life, health, property or the environment*." (IAEA, 2019, p.148)

Adverse psychological effects have been observed after every serious nuclear emergency that occurred in the past. Affected population is often confronted with feelings of future uncertainty, concern about residence and workplace safety and is commonly a victim of social prejudice. General fear of radiation coupled with inconsistent, confusing, or insufficient information received during the emergency has shown to fuel mistrust in the experts and the authorities, as well as evoke the feeling of vulnerability and loss of control of one's own life. Such conditions have, in turn, resulted in vast numbers of individuals taking unnecessary, inappropriate or even harmful actions that would further aggravate the non-radiological consequences of the emergency. (IAEA, 2012b, p.42)

[21] i.e., actions aimed at restoring the agricultural areas to their initial state

It is essential that governments make careful arrangements for mitigation of both "*non-radiological consequences of a nuclear or radiological emergency and of an emergency response*" (IAEA, 2015d, p.44) Such arrangements must include:

- Measures to address public concerns at all stages of the emergency, including the post-emergency stage
- Measures to promptly identify and address any unwarranted, inappropriate, or harmful actions taken by the general population or the institutions[22]
- Medical and psychological counselling during the emergency as well as suitable long-term arrangements for the post-emergency stage
- Establishment of a commensurate and a sustainable social support system

Sources: (IAEA, 2003, pp.86–87; 2015d, pp.44–45)

4.4. Infrastructural requirements

Chapter 4.3. looked closely into arrangements that need to be put in place to fulfill all the *functional* requirements of nuclear emergency preparedness and planning. The following chapters will focus on the *infrastructural* elements that need to be established and maintained in order to enable the execution of all the functional arrangements discussed in previous chapters.

4.4.1. Authority

There have been examples in the past where a crucial response action was not carried out or was significantly delayed since there was not an individual or a body on site with the authority and the responsibility to declare the action necessary and enforce it. Governments must therefore ensure that the "*authorities for developing, maintaining and regulating arrangements, both on the site and off the site, for preparedness and response for a nuclear or radiological emergency*" are established, and that "*by means of acts, legal codes or statutes*". (IAEA, 2015d, p.48)

All functional arrangements and provisions described in chapter 4.3. must be delegated to appropriate operating and response organizations on a local, regional, and national level, taking into account the possibility of transboundary emergencies, where necessary.

[22] both governmental and non-governmental

Furthermore, the resulting system must be documented, listing and elaborating all the assigned functions and roles, authorities and responsibilities during all stages of a nuclear emergency. Ultimately, organizations and individuals with assigned authorities must acknowledge, understand, and officially agree on the roles and authorities of all other individuals and organizations involved in emergency response. That way, all potential conflicts, overlaps or redundancies within the hierarchy can be uncovered and resolved at an early stage. (IAEA, 2015d, pp.48–49)

Arrangements must also be made to allow for continuous communication and coordination between all infrastructural elements in all phases of emergency response, more of which will be discussed in chapter 4.4.3. Consequently, *authority* must be assigned for all communication and coordination-related activities, most notably the authority to provide direction and overall coordination of the entire response effort, as well as the settlement of conflicts between different response organizations. Those individuals and organizations who have been assigned authority over critical response actions must not be given any additional roles. (IAEA, 2012b, pp.45–47; 2015d, p.49)

4.4.2. Organization and staffing

Infrastructural arrangement for emergency response to a nuclear accident do not end with the delegation of authority. Whereas the previous chapter looks into *who* performs certain response actions, this chapter will examine *how* the actions are to be carried out and which infrastructural elements must be in place to allow for an effective emergency response.

Governments must ensure that organizational relationships and interfaces are established between each organization involved in nuclear EPR, whether on local, regional, national, or international level. Additionally, governments should ensure that the established organizational infrastructure is feasible in terms of staffing with qualified personnel. (IAEA, 2003, pp.92–93)

To better understand the requirements presented in this chapter, a distinction must be made between the terms *position* and *function*. In the previous chapter, the importance of functions for emergency preparedness and response was discussed, function referring to an individual's or organization's *purpose* within the system. Position, on the other hand, refers to an administrative post that enables the individual or the organization to fulfill its assigned function. In other words, *position* is an organization term – one needs to be assigned an official position within the organizational infrastructure to be able to carry out one's function as laid out in the previous chapter.

Consequently, governments must ensure that *positions* in charge of carrying out functions described in chapter 4.3. are assigned within every operating and response organization as well as in regulatory bodies, and that they are integrated into emergency plans and procedures[23]. Furthermore, qualified personnel should be appointed to the assigned positions and should regularly be assessed for fitness to carry out their respective tasks. Governments must make arrangements that guarantee adequate numbers of qualified personnel are always at disposal[24] and all the necessary positions within the organizational structure are promptly staffed following a declaration of emergency, including the personnel tasked with carrying out long-term actions in the post-emergency stage. (IAEA, 2015d, p.50)

4.4.3. Coordination

There are two aspects to the coordination of nuclear EPR: a) *internal coordination*, i.e., coordination between the operating organization, response organizations and different institutions relevant for emergency response on a local, regional, and national level, and b) *external coordination*, i.e., coordination with other states and the international community. Governments must ensure arrangements are made that enable continuous coordination between these elements during all stages of emergency, including the preparedness and the post-emergency stage. (IAEA, 2003, pp.94–96)

Internal coordination

It has already been said in the previous two chapters that a clear delegation of authority, roles, and functions, as well es the assignment of positions and the establishment of organizational relationships and interfaces between participating organizations is crucial for the EPR infrastructure. After all the requirements listed in the previous two chapters have been fulfilled, particular attention must be given to *coordination* of the arrangements.

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[23] Emergency plans and procedures will be discussed in more detail in chapter 4.4.4.

[24] 24 hours a day, 365 days a year.

First step is to ensure meticulous documentation of all the arrangements and protocols[25], their availability to all parties concerned, and their inclusion in national emergency plans. Continuous revision and cross-referencing must be performed to assure the working relationship between all parties is as effective as it can be. It should be clearly defined which organizations are to work together, where they are to interact and how they are to communicate. Special diligence is required for coordination of protocols with organizations for *conventional* emergency planning and response[26]. All tools and procedures used during response to the same emergency must be harmonized to ensure uniform results are produced when assessing contamination, doses or health effects. (IAEA, 2015d, p.51) An existing or a newly established governmental body should be designated as a national coordinating authority, duties of which have been explained in detail in chapter 4.2.1.

The importance of internal coordination has been confirmed by past emergencies that have given us examples of delays in response and great confusion being caused by the fact that response organizations were not always aware of the roles other participating organizations had, or did not acknowledge those roles, which led to conflict. Additionally, there are several examples of a reverse situation – authorities or organizations incorrectly assuming their roles and acting out of place. It is precisely situations like these that can lead to public mistrust and increased fears during and after a nuclear emergency.

External coordination

All requirements for achieving internal coordination of EPR procedures apply equally to coordination with other states and the international community. Harmonization of all criteria, procedures and tools used for assessing the state of emergency and the required response levels is necessary, so as not to create confusion and further complicate the already challenging task of transnational communication. (IAEA, 2003, p.95) In the event of a transboundary nuclear emergency, arrangements should be in place to coordinate all protective, mitigatory or other actions recommended to the citizens and the embassies. This is to ensure that information and instructions conveyed to the public are consistent across borders. Additionally, arrangements need to be made to understand the logic

[25] A written protocol can take on a form of an agreement, a memorandum of understanding etc.
[26] This includes the police force, firefighters, military etc.

behind any national deviations and convey this information to the public and the media in plain language. (IAEA, 2015d, p.51) When areas in threat category V extend beyond the national borders, all potentially affected states must develop their own EPR plans, based on information provided by the government of the state hosting the facility. (IAEA, 2003, p.96)

4.4.4. Plans and procedures

Past experiences have shown that if the staff had failed to recognize the severity of the emergency and, by extension, provide appropriate response, it was due to flawed plans and procedures that did not account for worse-case scenarios and the lack of predetermined criteria based on which events could be classified. Governments must ensure that preestablished plans and procedures for all potential scenarios are developed and the personnel *at all levels* is made familiar with them.

As previously shown in Figure 7, plans and procedures that form a national radiation emergency plan are part of a complex system that exists under the all-hazards approach. Consequently, there is a multitude of elements that need to be considered, arranged, and documented for the emergency infrastructure to operate smoothly as a whole. Many of those elements have already been discussed in chapters 4.4.1. – 4.4.3. The following paragraphs will list and describe *additional* elements that need to be included in nuclear emergency plans and procedures.

An organization needs to be selected or established that will develop, coordinate, and maintain all national emergency arrangements. Although all response organizations are tasked with developing their own plans and procedures, it is still necessary to integrate all those plans in one national emergency plan in a coordinated manner. Under the all-hazards approach, special consideration is given to the fact that a nuclear emergency may be accompanied by other types of emergencies, e.g., natural disasters or security events. In such cases, other emergency response actions may need to be implemented simultaneously and must not cause conflicts with national radiation emergency plans or reduce their efficacy. (IAEA, 2015d, p.52)

The responsibilities of each operating and response organization must be documented in the emergency plans, including detailed descriptions of how those responsibilities are to be discharged on and off the site as well as beyond the national borders. In the early preparedness stage, a *concept of operations*[27], i.e., a theoretical 'ideal response' to an emergency needs to be devised in order to ensure that everyone involved in building a national nuclear emergency infrastructure shares common understanding. (IAEA, 2003, p.20) Additionally, plans and procedures shall never be developed without continuous input of those who will execute them. It is only when all relevant organizations and individuals are involved in the process that false assumptions about responsibilities and capabilities can be identified and mutual understanding as well as allocation of resources can be achieved. (IAEA, 2012b, pp.51–52)

4.4.5. Facilities and logistics

The logistical support during a nuclear emergency refers to the provision of all supplies, tools, instruments, equipment, technology, and documentation[28] necessary for an efficient and successful implementation of emergency plans and procedures. 'Facilities' in the context of emergency response are understood as places, more particularly buildings, designated to serve as control centers, on- or off-site coordination centers, public information centers, laboratories etc. (IAEA, 2007, p.44) Both facilities and logistical elements that exist under normal conditions are not adequate during emergency situations, the best example being the collapse of communication channels such as land lines and mobile networks that often occurs in the vicinity of emergency sites. This is why it is the responsibility of governments to "*ensure that adequate logistical support and facilities are provided to enable emergency response functions to be performed effectively in a nuclear or radiological emergency*". (IAEA, 2015d, p.54)

The following aspects of logistical support in a nuclear emergency have been identified as the most vital:

- Identification of resource requirements that a wide range of events could place on organizations responding to nuclear emergencies
- Adequate equipment and facility training of emergency teams in all response organizations

[27] The IAEA has developed a concept of operations for each threat category that can be used by States as a baseline and then further adapted to fit the country-specific conditions. (IAEA, 2007)
[28] e.g., manuals, telephone directories, checklists etc.

- Availability of equipment that is fit for use in the field under various challenging conditions
- Continuous availability of stable communication channels that provide various options for telecommunication and have embedded *redundant* systems as well as the capability to harmonize radio frequencies
- Alternative water and electric power supply for facilities in threat category I and II

Sources: (IAEA, 2003, pp.102–105; 2012b, p.55)

In order to support emergency response, following locations or facilities must be designated and provided with all the necessary resources for uninterrupted operation:

- Notification and initial response center
- Coordination center for on-site response
- Coordination center for off-site response[29]
- Center for provision of technical and operational assistance to on-site and off-site response personnel
- Center for national response coordination
- Center for public information coordination
- Center for coordination of environmental monitoring, sampling, and analysis
- Laboratories for emergency analysis of environmental samples
- Evacuation management center
- Resource management center
- Medical center

Sources: (IAEA, 2003, pp.102–105; 2015d, pp.55–56)

A high degree of cooperation is required between all the facilities listed above to ensure they function as one integrated system under a wide range of hazardous conditions, without redundancies or conflicting functions. It is also important to ensure that they are *physically separated* from the control room and the supplementary control room in facilities in threat category I.

[29] There must be a tight cooperation between centers for on-site and off-site response coordination

4.4.6. Training and exercises

Virtually all nuclear events in the past that required emergency response have uncovered areas in which personnel lacked training. Therefore, it is the duty of governments to ensure arrangements are made for all relevant emergency response personnel to "*take part in regular training, drills and exercises to ensure that they are able to perform their assigned response functions effectively in a nuclear or radiological emergency.*" (IAEA, 2015d, p.56)

Several common problems with training and exercises have been uncovered through analysis of the response to past nuclear emergencies. Firstly, individuals in high positions such as senior government officials often do not receive any training and are thus unable to provide adequate leadership in case of a nuclear emergency. Additionally, training had often been insufficient or completely omitted because it had not been regarded as a matter of high priority. Refresher trainings had commonly been omitted as well due to their repetitiveness and their failure to introduce new elements to the participants. Another issue with trainings and exercises is that they were often undertaken under unrealistic conditions or that they did not include all individuals and organizations that would participate in an actual emergency response. Ultimately, many trainings and exercises in the past have failed at developing team skills among the personnel as they were too focused on building individual response capacities.

It is the responsibility of both operating and response organizations to 1) *identify* all the knowledge, skills and capabilities personnel at every level must have in order to meet all the functional requirements of nuclear EPR, 2) *provide training* to all personnel, designed to instill said knowledge, skills and capabilities, 3) ensure that *refresher training* takes place continuously, at appropriate time intervals. Additionally, operating and response organization must cooperate with the government to ensure that specified training is given to individuals who do not normally handle ER but are assigned important leadership positions in cases of nuclear emergency, e.g., mayors or prime ministers. In the same manner, arrangements need to be made for conventional emergency responders such as police officers, firemen or military officers to receive training on the radiological aspects of the response. For facilities in threat categories I and II, visitors such as cleaning staff or construction workers must also be given instructions on the appropriate course of action in case of an emergency. (IAEA, 2003, pp.106–108)

In addition to trainings, it is the shared responsibility of the government, operating and response organizations to develop and implement regular *exercises and drills* to test the efficiency of nuclear emergency response and identify potential areas for improvement. The exercises and drills should include all organizations involved in emergency response, potentially affected population as well as representatives of news media. Staff with critical response functions, off-site officials deciding on protective and other response actions, and public information officers need to participate in exercises and drills on a regular basis i.e., at minimum once a year. (IAEA, 2015d, pp.56–57)

4.4.7. Quality management

Functional requirements for nuclear emergency response described in chapter 4.3. and the supporting infrastructural elements described in chapter 4.4. create a highly complex, multifaceted network that needs to be continuously examined and rigorously maintained to ensure adequate response can take place in case of an actual emergency. Governments must ensure that all operators as well as response organizations establish a program that will 1) guarantee adequate provision of *logistical support* and *facilities*, 2) *review* and *revise* plans and procedures, 3) ensure adequate and continuous *training* is provided to all relevant staff, 4) identify and incorporate knowledge acquired from research, exercises, and operating experience, both local and international, and 5) arrange for recurrent internal and external *audits* of EPR infrastructure as a whole. If internal audits or evaluations of performed exercises produce lessons that can be considered of international relevance, they must be reported to the IAEA and other international organizations. (IAEA, 2003, pp.109–110; 2015d, pp.57–58)

5. Key requirements missing from the IAEA portfolio

Chapter 3 identified five specific challenges for nuclear EPR in sub-Saharan Africa which stem from the region's unique geopolitical circumstances. The analysis of those challenges made it clear that the general, functional and infrastructural requirements outlined by the IAEA do not suffice in the context of sub-Saharan Africa, as they fail to account for some basic infrastructural elements which need to be in place to even allow for the development of nuclear EPR infrastructure. Chapters 5.1.-5.5. will introduce a new set of requirements based on main findings from chapter 3.

5.1. Good governance

Transparent, accountable and effective governance is the backbone of nuclear EPR infrastructure. Several models which break down governance into constituent elements are in use globally. For this thesis, World Bank's six-element model (Figure 3) will be used to highlight why good governance is critical for effective nuclear EPR arrangements and which requirements relating to governance nuclear newcomer countries in sub-Saharan Africa should be subject to.

Voice and Accountability

During nuclear emergencies, citizens' ability to voice concerns, access accurate information, and hold authorities accountable is essential. Public trust in government communication is crucial when providing information about radiation risks, protective measures and courses of action for the affected population. Countries which score low on this governance indicator must put in significant efforts to promote freedom of expression and media independence, strengthen civil society by encouraging *civic education* and engaging with watchdog organizations, foster a *responsive bureaucracy* and encourage *transparency* by enacting access to information laws and engaging citizens in decision-making.

Political Stability and Absence of Violence

Countries hosting nuclear power plants require a stable political environment for two reasons: 1) to minimize the risk of nuclear emergencies occurring and 2) to ensure effective coordination and decision-making in the event of nuclear emergency. Political instability, conflicts, or violence can disrupt response efforts, endangering both the public and responders and further aggravating the consequences of the accident. Stable governance on the other hand allows for the establishment of clear chains of command, cooperation among response organizations, and the maintenance of law and order in affected areas. Countries which score low on this governance indicator should not embark on nuclear journeys before implementing strong measures to *prevent conflicts* and address underlying grievances, *strengthen law enforcement* agencies, promote *inclusive political dialogue* and peaceful resolution of conflicts, and engage civil society in conflict prevention and peace-building efforts.

Government Effectiveness

Only effective government institutions have the capacity to plan, coordinate, and execute response efforts during a nuclear emergency, including evacuation, decontamination, and short- and long-term medical treatment. Countries which score low on this governance indicator should implement reforms to *streamline bureaucracy* and increase the efficiency of public administration, invest in *capacity building*, and work on improving the delivery of *public services*.

Regulatory Quality

Regulatory quality directly impacts the safety and resilience of nuclear installations in a country as well as the effectiveness of nuclear EPR arrangements. Sound regulatory framework with robust enforcement mechanisms is crucial for ensuring that safety standards are maintained and safety protocols are followed. Countries which score low on this governance indicator should implement measures to strengthen regulations related to safety as well as their *enforcement*, encourage a culture of safety by conducting regular inspections and *penalizing violations,* and provide *public access to regulatory processes* in order to enhance accountability.

Rule of Law

Similar to regulatory quality, strong rule of law in a country is fundamental for reducing the risk of nuclear accidents occurring by ensuring that nuclear facilities maintain safety standards and adhere to safety protocols. Additionally, it provides a legal basis for addressing disputes and establishing mechanism for liability and compensation in the aftermath of a nuclear accident. Countries which score low on this governance indicator should undertake *reforms* to strengthen their legal frameworks, promote culture of accountability by holding individuals and institutions *accountable* for violations of the law, promote *legal education and awareness* among the population and improve *access to justice* for all citizens.

Control of Corruption

Corruption can seriously jeopardize nuclear emergency preparedness and response by diverting resources, compromising safety inspections, and eroding public trust in governmental institutions. Countries which score low on this governance indicator should introduce strong anti-corruption measure and promote transparency, particularly when it comes to procurement processes and financial transactions, as well as ensure that strong accountability mechanisms are in place.

5.2. Good economic performance

Strong economic performance is crucial for countries hosting nuclear power plants as it allows for adequate allocation of resources, investment in safety protocols, maintenance of a dynamic and skilled workforce, and establishment of a robust nuclear EPR infrastructure. Solid economic foundation contributes to risk minimization and helps ensure the feasibility of emergency response plans. On the other hand, low economic development contributes to vulnerability since the population affected by poverty has a limited capacity to implement risk-reducing measures. Additionally, countries with poor economic performance need to allocate a large portion of the national budget to basic social services such as health, education and poverty alleviation, making it difficult to prioritize funding for nuclear safety. Lastly, nuclear power plants are a long-term commitment due to their long lifespans. A decades long financial obligation to maintain nuclear EPR infrastructure can be particularly challenging for countries with unfavorable economic conditions.

Countries with low economic development should only embark on nuclear journeys after comprehensive feasibility studies have been done, as well as significant investments in basic infrastructure such as transportation and communication networks. Additionally, adequate funding must be secured, not only for construction, operation and decommissioning of nuclear power plants, but also for the development and maintenance of all safety features, including nuclear EPR infrastructure. Lastly, governments must ensure that national economic conditions are reflected in the nuclear EPR arrangements, with special provisions put in place to acknowledge and protect the vulnerable population.

5.3. Strong human capital development

Strong human capital development is another backbone of a country's nuclear EPR infrastructure. In order to prevent accidents, manage crisis if they occur, and ensure long-term safety of nuclear power generation, an *exceptionally diverse* and well-trained workforce is needed. In addition to nuclear professionals such as engineers, radiation protection specialists, decontamination specialists, radiological assessors etc., a plethora of *non-nuclear professionals* are also required: emergency planners and managers, security personnel, first responders, medical professionals, environmental scientists, information technology specialists, public information officers, legal experts, social workers, psychologists and counselors, civil engineers, chemists, meteorologists, GIS specialists, logistics and supply chain experts etc. Additionally, it is essential that the public perceives those professionals as competent and trusts the quality of their education.

This task can be particularly challenging for nuclear newcomer countries with poor human capital and educational statistics which is why they should prioritize education as a fundamental investment. Improving access to quality education across all relevant disciplines, enhancing vocational training and promoting *lifelong learning* should be the main focal points for governments. An additional impetus to prioritize education should come from the fact that a poorly educated general public poses an additional hazard during emergencies.

Lastly, although collaboration with the IAEA and experienced nuclear nations is encouraged in the initial stages of nuclear development as it helps build and share expertise, countries which have committed to introducing nuclear power into their energy mix need to, in later stages of nuclear development, gradually decrease their reliance on third parties when it comes to principal education of their nuclear workforce.

5.4. Good health systems performance

The IAEA already acknowledges the need for countries to ensure medical professionals in the vicinity of nuclear facilities receive specialized training and that medical centers are adequately equipped to deal with potential influx of patients with radiation injuries. However, even when those conditions are met, medical response to a nuclear emergency may still be inadequate if the overall health-systems performance in the country is poor.

Low-performing health systems are characterized by limited public access to healthcare, inadequate and insufficient facilities, medication shortages, inefficient healthcare delivery, weak health information systems and shortages of skilled workforce – all of which pose a significant concern in context of nuclear emergency preparedness and response. General public in countries with poor health-systems performance is more prone to panic, more susceptible to misinformation, less likely to follow the instructions issued by the authorities and is more likely to delay seeking medical treatment, be it due to cost, lack of access or lack of awareness. Additionally, low-performing health systems are not in best position to address all the long-term medical needs of patients with stochastic health effects.

In order to build a solid basis for nuclear EPR, countries should perform comprehensive assessments of their health systems to identify the most critical areas in need of improvement and should then secure sufficient funding to support the reform. Public health campaigns should be conducted in order to educate the general public about health-seeking behaviors and the importance of official health guidelines. Lastly, significant investments are necessary in healthcare infrastructure, workforce expansion, and the strengthening of health information systems.

5.5. Well-developed basic infrastructure

Even if all IAEA's nuclear EPR requirements described in chapters 4.2.-4.4. were fulfilled, a country's response to a nuclear emergency would falter as long as basic national infrastructure remains deficient. Well-developed transportation and communication networks as well as water and sanitation facilities are of utmost importance for nuclear emergency preparedness and response – they provide the fundamental groundwork for it. Communication breakdowns resulting from unreliable or limited communication infrastructure can lead to delayed alerts, miscommunication, and difficulties in conveying critical information to the public and responders during a nuclear emergency. Underdeveloped transportation infrastructure, particularly roads and vehicles, can lead to delays in the deployment of emergency responders, equipment, and supplies to the affected areas and can seriously impede evacuation efforts, increasing the exposure risk. In addition to hampering decontamination efforts, substandard or limited water and sanitation facilities pose an additional health hazard in the aftermath of nuclear emergencies.

In order to create a solid basis for the nuclear EPR infrastructure, it is imperative for nuclear newcomer countries to invest in the development of road networks, public transportation systems, reliable communication networks, and state-of-the-art water and sanitation facilities accessible to all. It must also be acknowledged that addressing basic infrastructure deficits is an endeavor which requires strong political will, public support, strategic planning, immense financial resources, and, given the monumental scale of the task, substantial improvements are only achieved after many years of continuous efforts. Countries should adjust their nuclear ambitions accordingly.

6. Single-country weighted assessment model for nuclear EPR in sub-Saharan Africa

Chapters 4 and 5 introduced and described all the nuclear EPR requirements for countries in sub-Saharan Africa by combining IAEA guidelines with the analysis of past nuclear emergencies as well as region-specific challenges. Total of 21 elements for a complete and effective nuclear EPR infrastructure were identified. However, some of these elements are more significant than the others and must therefore be prioritized. In order to more accurately assess countries' readiness to respond to potential nuclear emergencies, a weighted approach is necessary. Table 6 presents a weighted assessment model developed specifically for this purpose.

Table 6: Single-country weighted assessment model for nuclear EPR in sub-Saharan Africa

Requirement	**Short description**	**Weighting factor**	**Score (0-100)**	**Weighted score[30]**
Basic responsibilities	Adoption of legislation clearly allocating responsibilities: operator, off-site officials, national coordinating authority	0,10	0-100	10
All-hazards approach	Integration of nuclear EPR arrangements into an all-hazards emergency management system	0,05	0-100	5
Threat assessment	Regular execution of threat assessments with periodical result reviews and subsequent development of protection strategies	0,06	0-100	6

[30] Maximum possible value

Identify, notify, activate	Identification and classification of the emergency, announcement of emergency class, response activation, off-site notification point	0,10	0-100	10
Urgent protective actions	Arrangements for isolation, evacuation, sheltering, decontamination, exposure prevention, medical response	0,09	0-100	9
Communication with the public	Designation of a public information center and news media liaison officers, provision of useful, correct and timely information	0,06	0-100	6
Medical response	Medical staff training, designation of medical centers in charge of patient treatment, arrangements for long-term care	0,05	0-100	5
Agricultural measures	Arrangements for environmental monitoring, contamination prevention, ingestion prevention, enforcement of restrictions	0,04	0-100	4
Mitigation of non-radiological consequences	Arrangements to identify and address harmful public behaviors, medical and psychological counselling, social support system	0,03	0-100	3
Authority	Delegation of all functional EPR arrangements to appropriate operating and response organizations at all levels	0,10	0-100	10
Organization and staffing	Establishment of organizational interfaces between all response organizations, assignment of positions, adequate staffing	0,08	0-100	8
Coordination	Documentation and *harmonization* of all EPR arrangements and protocols, arrangements for international cooperation	0,10	0-100	10
Plans and procedures	Development, description, documentation and regular updates	0,08	0-100	8

	of all EPR plans and procedures, concept of operations,			
Facilities and logistics	Provision of supplies, instruments, tools, equipment, technology, and *independent* response, management and coordination facilities	0,07	0-100	7
Training and exercises	Design and execution of regular training, exercises and drills for all emergency response personnel and other relevant officials	0,06	0-100	6
Quality management	Examination and maintenance of the entire nuclear EPR network, internal and external audits	0,05	0-100	5
Good governance	Voice and accountability, absence of violence, political stability, rule of law, regulatory quality, corruption control, government effectiveness	0,09	0-100	9
Good economic performance	High GDP per capita, low inflation rate, low unemployment rate	0,12	0-100	12
Strong human capital development	High human capital index, good education statistics	0,06	0-100	6
Good health systems performance	High health systems performance index, high resilience	0,05	0-100	5
Well-developed basic infrastructure	Well-developed transportation and communication infrastructure, high access to safely managed water and sanitation facilities	0,12	0-100	12
			Total possible score:	**156**

To utilize the proposed model for assessment, each of the 21 requirements listed in the table should be examined individually. A score ranging from 0 to 100 is assigned to each requirement, reflecting the degree to which it is fulfilled in the country of assessment. Additionally, a weighting factor is assigned to each requirement, signifying its relative importance in the overall assessment. To calculate the country's readiness level to respond to nuclear emergencies, the score for each requirement is multiplied by its respective weighting factor. The resulting values are then summed to obtain a comprehensive assessment score, providing a quantitative measure of the country's nuclear EPR infrastructure performance. This approach allows for a more nuanced assessment that considers both the importance of each requirement as well as the country's performance in meeting them. To be considered as having a solid capacity to respond to nuclear emergencies, the country should score at least **85%** of the total 156 points.

The weighed assessment model introduced in this chapter will be applied during the final stage of the case study examining the state of nuclear EPR infrastructure in the Republic of Ghana, presented in chapter 7 of the thesis.

7. Case study: Ghana

For the case study, three nuclear newcomer countries in sub-Saharan Africa were considered: Ghana, Kenya, and Nigeria[31]. All three countries have committed to introducing nuclear power into their energy mix within the next two decades and have made significant progress with IAEA's Milestones Approach, all successfully implementing Phase 1. After careful consideration, Ghana was chosen for the case study for two main reasons: 1) having made the most progress as well as having the most ambitious goal[32] among the three candidates, and 2) positive engagement exhibited by local nuclear authorities in facilitating cooperation and answering to inquiries.

The case study consists of four parts:

1. *Country profile* which will showcase and contextualize Ghana's performance in some of the most important development indicators linking them to nuclear emergency preparedness, as well as provide a brief nuclear history of the country.
2. *IAEA EPREV Mission 2015: Findings* which will summarize and analyze key observations made by the IAEA experts after a careful review of country's EPR infrastructure during the 2015 EPREV Mission to Ghana.
3. *Independent progress review 2023: self-administered questionnaire* which will investigate, assess, and quantify progress that has been made in the country after the 2015 EPREV Mission.

[31] Formally: Republic of Ghana, Republic of Kenya, Federal Republic of Nigeria (United Nations, 2023a)
[32] Ghana plans to introduce nuclear power into the energy mix by 2030 (Dontoh, 2023)

4. *Weighed assessment of nuclear EPR infrastructure* which will apply the single-country weighed assessment model proposed in chapter 6, results of which should shed light on the realistic state of nuclear EPR infrastructure in the country.

The methodologies employed for the first two parts of the case study will encompass open data analysis and comprehensive literature review. For the third part, the investigative approach will involve administering custom-made questionnaires and conducting interviews with experts from Ghana's Nuclear Regulatory Authority (NRA). Lastly, a weighted assessment model will be applied to examine the country's current capacity to respond to nuclear emergencies.

7.1. Country profile

Ghana's nuclear history starts in 1963 with the establishment of Ghana Atomic Energy Commission (GAEC), which has been successfully operating a small research reactor since 1994. In 2006, School of Nuclear and Allied Sciences was jointly established by GAEC and the University of Ghana, with the goal of training nuclear scientists and establishing nuclear workforce for the future. Other important milestones include the establishment of Ghana Nuclear Power Programme Organisation (GNPPO) in 2012 to serve as a coordinating body for the development of national nuclear infrastructure and the subsequent establishment of GAEC's Nuclear Power Institute (NPI)[33] in 2014, which was to serve as technical support. (IAEA, 2022a, p.27)

The National Nuclear Regulatory Authority (NRA) was established through the 2015 National Nuclear Regulatory Authority Act and began operations in 2016, taking over the functions previously performed by GAEC's Radiation Protection Board (RPB). (NRA, 2023) Ultimately, Nuclear Power Ghana (NPG) – the owner and operator-to-be of the nation's first nuclear power plant – was established in 2018. (NPG, 2023) In 2020, Ghana successfully finalized Phase 1 of IAEA's Milestone's Approach and is currently within Phase 2.

In summary, the three main stakeholders in Ghana's nuclear landscape at present are:

[33] At the date of its establishment, the Nuclear Power Institute was called Nuclear Power Center. The name change took place in 2015. (IAEA, 2022a, p.27)

1. NPG – future owner and operator of the nuclear power plant
2. NPI – technical and scientific support organization (TSO) in charge of aiding the development of Ghana's nuclear infrastructure, including human resource capacity, knowledge, and technology
3. NRA – the regulatory body

When it comes to nuclear emergency preparedness, there is no universally applicable approach as every country faces a different set of challenges and is characterized by a distinct combination of external factors. To understand each country's unique emergency planning needs, wider context needs to be provided. The following infographic showcases some of the most important development indicators discussed in previous chapters, with focus on Ghana. The data shown has been collected from the World Bank Open Data online platform.

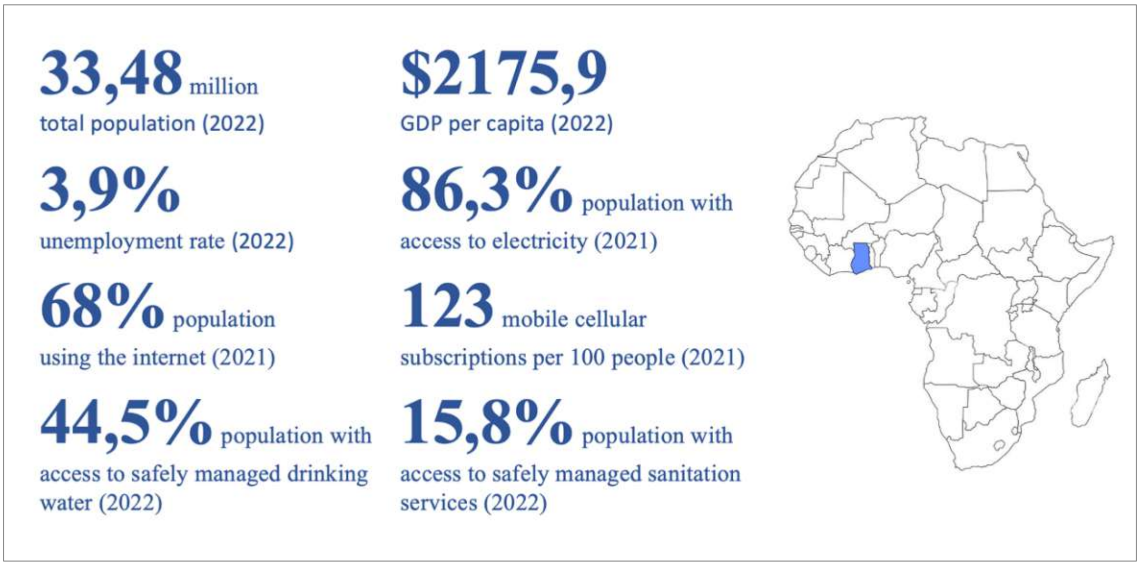

Figure 8: Country Profile – Ghana

Ghana's population of 33,48 million has an incredibly youthful profile, with around 57% of population being under the age of 25. (CIA, 2023) This particular statistic is important for being able to interpret the country's unemployment rate which, although sitting relatively low according to global standards, cannot automatically be seen as a sign of stability. Youth unemployment in Ghana, measured at 7,1% in 2022, is nearly twice as high as the overall unemployment rate. (World Bank, 2023c) Additionally, the rates of underemployment and informal employment remain quite high as well as the portion of population in vulnerable employment. (Ghana Statistical Service, 2023) The amalgamation of these factors indicates that challenges will likely escalate in the near future, as more and more youth enter the labor force.

As previously discussed in chapter 3.2, all these statistics provide a better context for understanding the country's nuclear emergency preparedness needs. GDP per capita of $2175,9 places it in the lower-middle-income category and the statistics showing the access to safely managed water and sanitation services accurately depict the country's struggle with growing population in an environment characterized by outdated or inadequate infrastructure. Although mobile cellular subscriptions in Ghana are very high, population with the access to internet is still relatively low, raising concerns regarding access to information and social connectivity – factors that are incredibly important in nuclear emergencies.

For a better context, in comparison to the country with the lowest development indicators among those currently operating commercial nuclear power plants, Ghana still scores significantly lower. This comparison is not intended to dissuade the pursuit of a nuclear power program in the country, but rather to underscore the immense coordinated and *cross-sectoral* effort that needs to be undertaken to elevate Ghana's infrastructure to a level conducive for the successful implementation of a nuclear power program.

7.2. IAEA EPREV Mission 2015: Findings

Thus far, Government of Ghana has requested IAEA Review Missions on three separate occasions:

- 2015 Emergency Preparedness Review (EPREV) Mission
- 2017 Phase 1 Integrated Nuclear Infrastructure Review (INIR) Mission
- 2019 Phase 1 INIR Follow-up Mission which assessed the implementation of suggestions and recommendations communicated during the 2017 mission.

Given that emergency planning is only one of 19 different aspects assessed during the INIR Missions, the focus of this case study will be on the results of 2015 EPREV Mission and the progress that has been made thereafter. Insights gathered through 2017 and 2019 INIR Missions will only serve as supporting literature for the progress assessment.

IAEA’s EPREV missions are conducted at the request of Member States and serve not as an audit but as a peer review of country’s EPR arrangements and capabilities based on IAEA’s most recent Safety Standards. In 2015, a 10-day EPREV Mission was carried out in Ghana, at the request of GAEC and the National Disaster Management Organization (NADMO). (IAEA, 2015a)

Although it had not yet been officially released at the time of the EPREV Mission in 2015, the main reference used for the assessment was IAEA Safety Standards Series GSR Part 7, which is a quintessential reference within the field of nuclear emergency preparedness today as well as a recognized international norm.

Following the structure of GSR Part 7, a team of IAEA experts and international EPR experts investigated how well Ghana was faring with regard to general, functional, and infrastructural requirements prescribed by the IAEA and detailed in chapter 4 of this thesis. Subsequently, a report was published, discussing the most important findings, and offering suggestions and recommendations for the relevant organizations. For the exact wording of all suggestions and recommendations, reference can be made to Annex 1. The following sections will provide a summary and a brief analysis of the most significant observations made during the Mission, which were the basis for all suggestions and recommendations.

Observations regarding general EPR requirements:

- The National Disaster Management Plan (NDMP) and the National Nuclear and Radiological Emergency Response Plan (NNRERP) are well devised but will need revision after the anticipated new legal basis enters into force.
- In its regulatory role, Radiation Protection Institute (RPI) lacks well-defined criteria and guidelines that would serve as a basis for their regulatory findings concerning EPR arrangements of operating organizations.
- In its regulatory role, Radiation Protection Board (RPB) does not consistently verify compliance of operating organizations with the obligation to develop and upkeep EPR arrangements for practices and facilities where nuclear or radiological emergencies could occur.

- National hazard assessment does not receive regular updates and does not contain an exhaustive list of all radioactive sources and their locations.
- Protection strategy for taking protective and other response actions in an emergency is not contained in the NNRERP.

Observations regarding functional EPR requirements:

- NADMO-designated Incident Command System (ICS) has clearly defined responsibilities for all operating and response organizations during a nuclear or radiological emergency, however, none of the staff have been trained to assume their responsibilities under the ICS.
- Most operating organizations do not have an emergency classification system and it is also missing from the NNRERP.
- There is no designated National Warning Point serving as a notification system between Ghana, other states, and the IAEA. Additionally, Ghana has not yet registered for IAEA's Unified System for Information Exchange in Incidents and Emergencies (USIE).
- Guidance on identifying and diagnosing radiation injuries is notably absent from medical curricula country-wide and remains unaddressed in professional development programs for medical staff.
- The hospital designated to provide medical care during a nuclear emergency does not have any staff trained to treat radiation injuries and the Ministry of Health does not have any provisions in place assuring swift and safe referral of potentially contaminated patients to the designated facility for medical treatment.
- No arrangements are in place for requesting international assistance, i.e., Ghana is not yet subject to Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency.
- NADMO does not perform systematic analysis of past emergencies and the emergency response, foregoing the opportunity to improve preparedness and enhance response strategies.

Observations regarding infrastructural EPR requirements:

- Operating and response organizations with assigned roles and responsibilities during a nuclear emergency are not sufficiently staffed with qualified personnel and no analysis has been performed to establish the minimum quantities and qualifications.

- Operating and response organizations have not devised precise emergency plans and procedures necessary to fulfill the roles assigned to them in the NNRERP – most notably the GHARR-1 and GAEC as its operator.
- A list of emergency equipment each response organization has at their disposal is included in the NNRERP, but it is incomplete, and updates are not performed regularly.
- Apart from NADMO, other response organizations (most notably GAEC) do not have their own emergency centers. Additionally, the Central Alarm Station is not operated around the clock and relies on power supply from one singular source, with no backup in place.
- As a result of inconsistent implementation or complete omission of NNRERP-mandated training programs for staff, only a small number of professionals are well-versed in nuclear and radiological emergency response arrangements. The absence of formal training is distinctly evident among first responder personnel.
- NNRERP does recognize the importance of emergency exercises and drills, however, they are yet to be performed for nuclear and radiological emergency scenarios.
- Quality management framework stipulated in the NNRERP is neither executed not documented.

As the key observations indicate, the status of Ghana's nuclear emergency preparedness and response infrastructure can be summarized as follows. The country has a solid emergency preparedness framework in place, albeit with a few integral elements missing. Nevertheless, a more *profound* understanding of the EPR arrangements is requisite across all constituent organizations, extending beyond a select cadre of experts. This requirement is particularly pronounced in relation to emergency plans and procedures of operating and response organizations, and how they integrate into NADMO's Incident Command System (ICS). Additionally, although the theoretical foundation of the emergency preparedness framework is sound, its practical implementation remains deficient across several sectors. Ultimately, the pivotal organizations within the EPR infrastructure exhibit an incomplete grasp of their own needs. Notably, a lack of clarity exists concerning the quantity of personnel required for the organizations to fulfill their mandate, the necessary qualifications for said personnel, as well as the equipment needed for effective response actions.

7.3. Independent progress review 2023: self-administered questionnaire

This chapter presents the methodology employed to conduct an independent assessment of the progress made in improving Ghana's EPR infrastructure subsequent to the IAEA's 2015 EPREV Mission as well as the results of this assessment. As previously mentioned, the Mission yielded five suggestions and fifteen recommendations for the relevant institutions, aimed at improving the country's nuclear EPR arrangements and based on the observations made during the Mission as well as the safety requirements from GSR Part 7. The chosen methodology entailed close collaboration with Ghana's Nuclear Regulatory Authority, realized through the distribution of a *custom-made* self-assessment questionnaire as well as a follow-up interview with Mr. Lennox Assan – Research Scientist at NRA's Emergency Preparedness & Response Department. The self-assessment questionnaire with its results, and the written version of the interview can be found in Annex 1 and 2, respectively.

The self-assessment form was structured into eighteen distinct segments, each aligned with an individual suggestion or recommendation from the 2015 Mission. It should be noted that 'Suggestion 3' was intentionally excluded from the self-assessment form due to the well-documented progress towards it in existing literature, while 'Suggestion 2' was excluded as it falls outside the scope of this thesis. NRA's Emergency Preparedness & Response Department, a pivotal entity in this study, carefully assessed the progress made in each segment. The respondents were requested to rate the progress earnestly and accurately using a five-point scale: 1. no progress, 2. very little progress, 3. some progress, 4. significant progress, and 5. complete progress. This approach is similar to the one used by the IAEA in their follow-up review missions. Moreover, the self-assessment form included an instructional component defining the benchmarks[34] for each of the five levels. The results are outlined below:

Table 7: Results of the independent progress review following the 2015 EPREV Mission

Suggestion / recommendation	**Progress level**
Suggestion 1: Review and revision of NDMP & NNRERP	Some
Recommendation 1: Criteria and guidance for regulatory judgement	Significant
Recommendation 2: Enforcement of obligations	Complete

[34] See Annex 1

Recommendation 3: Update of national hazard assessment	Significant
Recommendation 4: Development of protection strategies	Some
Recommendation 5: ICS training and exercises	Very little
Recommendation 6: Classification system for emergencies	Some
Recommendation 7: Designation of single warning point	Complete
Recommendation 8: Training for medical personnel	Some
Recommendation 9: Definitive care for contaminated patients	Some
Suggestion 3: International assistance[35]	Complete
Suggestion 4: Systemic analysis of emergencies	Some
Recommendation 10: Staffing and personnel	Complete
Recommendation 11: GHARR-1 emergency response procedures	Complete
Suggestion 5: Regular updates of EPR equipment list	Significant
Recommendation 12: Central alarm station and emergency center	Some
Recommendation 13: First responders training	Significant
Recommendation 14: Comprehensive exercise programs	Some
Recommendation 15: Quality management program	Significant

As the table demonstrates, the improvements achieved since 2015 vary, with five suggestions/recommendations being fully implemented, five where *significant* progress has been made, eight where *some* progress has been noted and only one with *very little* progress detected. Given that no segments were evaluated as having no progress at all, it can be inferred that improvement was attained in all aspects – at least to some degree.

To provide a clearer perspective on the extent of this improvement, the assessments were quantified into percentage values, reflecting the progress made towards each of the suggestions/recommendations. This quantification assigned specific percentage values to each level on the five-point scale: 'no progress' equated to 0%, 'very little progress' to 25%, 'some progress' to 50%, 'significant progress' to 75%, and 'complete progress' to 100%. It is necessary to acknowledge that while this quantitative approach increases the level of clarity, it does not offer a perfectly accurate representation of the quality and the

[35] Although not included in the self-assessment form, 'complete progress' was considered as the answer for Suggestion 3 given that Ghana had acceded to the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency in 2016. (IAEA, 2023b)

completeness of the work carried out by the respondents. Rather, it is adopted with the objective of providing a more accessible way to understand the extent of achieved progress.

To calculate the *overall* advancement since 2015, progress made in each of the segments was summed up and then divided by the total number of segments. Given the progress in each segment: 1 segment at 25%, 8 segments at 50%, 5 segments at 75%, and additional 5 segments at 100%, the overall progress can be calculated as follows:

Total progress = (1 * 25) + (8 * 50) + (5 * 75) + (5 * 100) = 25 + 400 + 375 + 500 = **1300**

Overall percentage of progress = (Total progress / Total number of segments) * 100 = (1300 / 19) * 100 ≈ **68%**

Therefore, the overall percentage of progress made towards the 19 suggestions and recommendations is approximately 68%. This quantitative result indicates that although progress was achieved in all aspects during the past eight years, there is much work left to be done within a short timeframe leading up to the 2030 goal. The 2015 EPREV Mission, although conducted within the constraints of a 10-day timeline, provided detailed observations; however, the resulting suggestions and recommendations should not be misconstrued as a definitive blueprint for achieving an impeccable EPR infrastructure. Even if 100% progress were made since 2015, one should not assume there are no further avenues for advancement. The suggestions and recommendations made in 2015 were specifically tailored to priorities identified at that time, reflective of the then-prevailing circumstances. Ghana would greatly benefit from a follow-up mission through which impartial experts could reassess both the progress and the present landscape. Updated recommendations are needed that take into account all the changes that have taken place in the past eight years, including new legal frameworks and the emergence of new core organizations within the nuclear program.

A follow-up interview with Mr. Lennox Assan of the NRA[36] reveals several reasons for slow progress in certain areas: 1) lack of financial resources, 2) lack of administrative

[36] See Annex 2

continuity, 3) management transition issues 4) intersectoral dependencies coupled with coordination gaps, 5) deficiencies in the medical sector, and 6) time constraints.

For complete implementation of recommendations 8 and 9, close cooperation with the institutions from the medical sector is necessary. However, this intersectoral dependency proves to be a major obstacle given the separate set of constraints and priorities Ghana's energy and medical sectors have. Similarly, many other recommendations and suggestions that have only been partially implemented also depend on cooperation between the NRA and other agencies, which has proven to be difficult due to frequent management changes, as well as the absence of clearly defined policies. All six of the reasons behind the slow progress can be associated with broader region-specific challenges identified in chapter 3 of the thesis, and could be seen as their manifestations. Economic challenges, deficiencies in the human resources sector, weak health systems performance, and lacking basic infrastructure seem to be at the core of the issue in Ghana's case.

Furthermore, a comprehensive analysis of NRA's Annual reports 2020-2021, which are available for download on the institution's webpage, confirms the prevalence of the same or similar key issues identified through the interview with Mr. Assan: 1) lack of financial resources, 2) limited and inadequate equipment, 3) substandard facilities, 4) lack of practical staff training, 4) insufficient staffing, 5) enforcement issues, 6) organizational and administrative inconsistencies and disruptions. (NRA, 2021a; 2021b; 2021c; 2022a; 2022b; 2022c) This farther supports the hypothesis that it is precisely the region-specific challenges identified in chapter 3 of the thesis that have been and will continue to impede the development of nuclear EPR infrastructure in the country and the region.

The ~68% overall progress determined through the independent review indicates that the nuclear EPR capacity in Ghana has increased since 2015, however, as this approach does not take into account the relative importance of each element in the overall EPR infrastructure, a graded assessment approach is necessary. By utilizing the graded assessment model developed in chapter 6, a more realistic appraisal of the country's current nuclear EPR capacity will be obtained.

7.4. Weighted assessment of nuclear EPR infrastructure

In this chapter, the meticulously constructed weighted assessment model presented in chapter 6 will be applied in order to evaluate the current state of nuclear EPR infrastructure in the Republic of Ghana. The model, as previously described, considers a comprehensive set of key requirements for a complete and efficient nuclear EPR network. By assigning scores from 0 to 100 to each requirement and multiplying them with their respective weighting factors, a nuanced and quantitative analysis should be attained of Ghana's capability to respond to nuclear emergencies. The scores were assigned based on the combined analysis of results of the 2015 EPREV Mission to Ghana and the independent progress review 2023, presented in chapters 7.2. and 7.3. For the last six requirements, the scores were calculated utilizing the most recent statistical data collected by the World Bank and the United Nations. In the process of score assignment (third column), it was deemed sensible to round numerical values to whole numbers as the assigned scores serve as *approximations* rather than precise measurements. On the other hand, the weighted scores (fourth column) are retained with two decimal places as they are the multiplication product of the weighted factor and the assigned score for each requirement. This level of precision is employed in order to produce a more detailed evaluation of each element's contribution to the overall assessment. The results are presented in Table 8.

Table 8: Results of the weighted assessment of Ghana's nuclear EPR capabilities

Requirement	**Weighting factor**	**Score (0-100)**	**Weighted Score**
Basic responsibilities	0,10	59	5,90
All-hazards approach	0,05	75	3,75
Threat assessment	0,06	69	4,14
Identify, notify, activate	0,10	50	5,00
Urgent protective actions	0,09	10	0,90
Communication with the public	0,06	90	5,40
Medical response	0,05	34	1,70
Agricultural measures	0,04	10	0,40
Mitigation of non-radiological consequences	0,03	50	1,50
Authority	0,10	25	2,50

Organization and staffing	0,08	75	6,00
Coordination	0,10	60	6,00
Plans and procedures	0,08	30	2,40
Facilities and logistics	0,07	70	4,90
Training and exercises	0,06	63	3,78
Quality management	0,05	61	3,05
Good governance	0,09	51	4,59
Good economic performance	0,12	39	4,68
Strong human capital development	0,06	50	3,00
Good health systems performance	0,05	49	2,45
Well-developed basic infrastructure	0,12	44	5,28
		Total:	**77,32**
		Percentage:	**~50%**

The assessment results provide valuable insight into the current state of nuclear EPR infrastructure in Ghana, highlighting the country's strengths as well as key areas where more work is required. Based on the current state of art, Ghana scores a total of 77,32 out of 156 possible points, or **~50%**, suggesting that its nuclear EPR capability is below average and that there is significant room for improvement, seeing as 85% is necessary for a solid nuclear EPR capacity. Additionally, this figure is notably lower than the ~68% obtained through the review of progress following the 2015 EPREV Mission, suggesting that the IAEA assessment methodology could also benefit from a graded approach for more realistic assessment results.

Furthermore, when looking at different categories of requirements, Ghana scores ~51% for general, functional and infrastructural requirements outlined by the IAEA and ~45% for requirements missing from the IAEA portfolio, further reiterating the need to revise the IAEA guides and manuals in order to address specific challenges of sub-Saharan nations. Similarly, the score for priority requirements[37] is only ~43% in comparison to ~57% for less relevant requirements, indicating a potential lack of strategic planning and inefficient allocation of resources. The progress is being made, but not where it is most

[37] Weighting factor 0,09 or higher

needed. This misalignment between the devoted efforts and the priorities of nuclear EPR infrastructure needs to be addressed going forward.

Moreover, it is worth noting that good performance is evident in a few of the categories, most notably arrangements for communication with the public, integration of the nuclear EPR arrangements into an all-hazards emergency management system and organization and staffing. On the other hand, a few critical categories exhibit an exceptionally low performance, most notably urgent protective actions and designation of authority, and should be made top priority moving forward. Additional areas that should be at the forefront of the development agenda are the arrangements for swift identification, notification and activation of emergency response, coordination mechanisms, development of plans and procedures, as well as investment in basic infrastructure and economic development initiatives. Better performance in these categories would significantly increase the country's overall assessment score.

Ultimately, while the foundation for the nuclear EPR infrastructure is in place and significant progress has been achieved during the past decade, the overall capability still falls below average. This is largely attributable to insufficient progress in most critical areas, which only underscores the necessity for the government and other relevant authorities to employ *strategic planning* and prioritize the most vital structural elements, allocating additional resources to address the critical deficiencies within them.

8. Summary and conclusion

To ensure a cohesive overview, it is important to revisit the subject matter presented in chapters 3-7 of this thesis. Chapter 3 identified and analyzed the main nuclear EPR challenges which are specific to the sub-Saharan region, and assessed their prevalence in nuclear frontrunner countries. Chapter 4 introduced the basic terminology and all the general, functional and infrastructural requirements for nuclear EPR outlined by the IAEA, demonstrating the exceedingly complex and intricate nature of this network, as well as highlighting the immense resources, expertise and coordinated inter-sectoral and inter-agency efforts required to build and maintain it. Subsequently, chapter 5 introduced nuclear EPR requirements which are missing from the IAEA portfolio and are *crucial* for an efficient response to nuclear emergencies, deriving them from the challenges identified in chapter 3. Combined findings from chapters 3-5 were then utilized in chapter 6 to develop a weighted model to assess the nuclear EPR capabilities of countries in sub-Saharan Africa. Lastly, this model was then used to evaluate, quantify, and analyze Ghana’s current capacity to respond to nuclear emergencies, in chapter 7.

8.1. Key findings

During the course of this thesis, numerous findings were made, with the most important highlighted below:

Sub-Saharan Africa

- Due to its distinct geopolitical circumstances, sub-Saharan Africa faces challenges for the development of nuclear EPR capabilities that set it apart from the rest of the world: 1) political instability, 2) poor economic performance, 3) human capital deficiencies, 4) weak health systems performance, and 5) basic infrastructure deficit.
- With a few minor exceptions, all of the identified region-specific challenges are at least moderately present in each of the nuclear frontrunner countries in sub-Saharan Africa, the majority of countries exhibiting high or very high prevalence.
- Even South Africa, which has been operating a nuclear power plant since 1984, exhibits moderate to high prevalence of three of the identified challenges which highlights the need to revise national nuclear EPR arrangements, particularly in light of their plans to upgrade nuclear capacity by 2030.
- The general, functional, and infrastructural requirements outlined by the IAEA and detailed in their guides and manuals have been a useful tool for nuclear newcomer countries in sub-Saharan Africa, however, they fail to address the region’s most pressing challenges; even if all the requirements are fulfilled, the country’s response capacity remains limited due to the missing elements.
- There are five additional requirements for a complete and effective nuclear EPR infrastructure which are missing from IAEA’s portfolio: 1) good governance, 2) good economic performance, 3) strong human capital development, 4) good health systems performance, and 5) well-developed basic infrastructure
- Good governance, good economic performance and well-developed basic infrastructure are so essential for nuclear EPR considerations that countries which

perform poorly in all three should *not* start operating nuclear power plants before improving their performance therein.

- Certain nuclear EPR requirements are more vital than the others as they create a foundation for the development of remaining infrastructural elements, which is why a weighted approach is necessary for capacity assessment, and strategic planning coupled with smart resource allocation is required from the governance standpoint.

Case Study Ghana

- The current socioeconomic and political environment in Ghana is not conducive for the development of nuclear EPR infrastructure and significant investments in basic infrastructure and economic development are necessary.
- Authorities in Ghana have made notable progress towards the suggestions and recommendations provided by the IAEA during the 2015 EPREV Mission, however, there is significant room for improvement in many of the key areas.
- The main issues the authorities encountered during their efforts to implement IAEA's suggestions and recommendations were: 1) lack of financial resources, 2) inadequate equipment and substandard facilities, 3) lack of administrative continuity and management transition issues 4) insufficient staffing and lack of practical training, 5) intersectoral dependencies coupled with coordination gaps, and 6) time constraints
- All the main issues the authorities encountered stem from the region-specific challenges, particularly from poor governance, low economic development, deficiencies in the human resources sector, as well as basic infrastructure deficits.
- IAEA's EPREV Mission in its current format does not suffice to assess nuclear EPR capacity of countries in sub-Saharan Africa as it fails to account for the region's unique socioeconomic and political circumstances and the associated challenges.
- Weighted assessment reveals that Ghana's nuclear EPR capability remains below average and can largely be attributed to insufficient progress in the most vital areas.
- The results and conclusions of the case study on Ghana are assumed to be applicable to other countries in sub-Saharan Africa.

8.2. Recommendations

Bearing in mind the combined findings from each stage of the conducted research, the following recommendations are put forward:

- Seeing as total of 22 countries in sub-Saharan Africa have expressed their nuclear power ambitions, the IAEA should revise their nuclear EPR requirements, guides, and manuals in order to address the region-specific challenges. This revision should also be reflected in the EPREV Mission.
- Countries in sub-Saharan Africa intending to pursue nuclear power should adjust their ambitions according to their performance in five key areas: 1) governance and political stability, 2) economic development, 3) human capital, 4) health systems, and 5) basic infrastructure development.
- Countries in sub-Saharan Africa who have already started to pursue nuclear power should recognize the criticality of good governance, good economic development, strong human capital, good health systems performance and well-developed basic infrastructure in the nuclear safety context, and should prioritize investment in these key areas going forward.
- Nuclear frontrunner countries in sub-Saharan Africa should recognize varying significance of different nuclear EPR requirements and should allocate additional resources and focus their efforts on improving performance in the most vital areas.
- Seeing as many countries in sub-Saharan Africa face similar challenges, the establishment of a regional nuclear organization the likes of Euratom is highly advised, as it could accelerate the development of national and regional nuclear EPR capabilities through knowledge exchange and resource sharing.
- The Government of Ghana should request a follow-up EPREV Mission without delay in order to receive *updated* suggestions and recommendations.
- Nuclear authorities in Ghana should focus on improving the following key elements of nuclear EPR infrastructure: 1) clear assignment of authority, 2) development of protection strategies and urgent protective actions, 3) development of arrangements for swift identification, notification and activation of emergency response, 4) improvement of coordination mechanisms, 5) development of plans and procedures, and 6) investment in basic infrastructure and economic development.
- The weighted assessment model should be used for future appraisals of nuclear EPR capacity in sub-Saharan Africa as it provides more realistic results than the models currently in use.

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Annex 1: Self-assessment questionnaire for the NRA, August 2023

Questionnaire: Nuclear and Radiological Emergency Preparedness in Ghana, 2015-2023

The purpose of this questionnaire is to assess the progress that has been made in relation to suggestions and recommendations provided by the IAEA during 2015 EPREV Mission to Republic of Ghana.

The questionnaire consists of 18 questions. For each question, consider the progress made in relation to IAEA's 2015 recommendation / suggestion.

There are 5 possible answers:

1) **No progress**: No action has been taken and no noticeable advancement has occurred.

2) **Very little progress**: Progress has been minimal and a lot more work is needed.

3) **Some progress**: There has been moderate advancement, but more work is needed.

4) **Significant progress**: Substantial improvement has been made.

5) **Complete progress**: The recommendation / suggestion has been wholly implemented.

Choose the answer that best reflects your **objective** assessment of progress for each question.

REMINDER!
At the time of the EPREV Mission in 2015, the NRA had not yet been established. Participants are kindly asked to consider each recommendation directed at GAEC as a recommendation directed at the NRA.

* Indicates required question

How much progress has been achieved towards **Suggestion 1**?*

Suggestion 1
Suggestion: NADMO and GAEC should consider reviewing and revising the NDMP and NNRERP in anticipation of the new legal basis, so that the arrangements can be in place as soon as practical after approval of the new bills.
Context:
Observation: The current emergency management system is well defined for all hazards, including nuclear and radiological emergencies. However, the new bills under review by Parliament will necessitate a revision to existing national plans.
Basis for suggestion: GSR Part 7, paragraph 4.1 states: "The government shall ensure that an emergency management system is established and maintained on the territories and within the jurisdiction of the State for the purposes of emergency response to protect human life, health, property and the environment in the event of a nuclear or radiological emergency."

○ No progress

- ○ Very little progress
- ● Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 1**?*

Recommendation 1
Recommendation: RPI, as the regulatory body, should develop criteria and guidance on which its regulatory judgements for operating organization EPR arrangements are based.
Context:
Observation: RPI, in the role of the regulator, does not have clear criteria or guidance on which to base its regulatory findings when reviewing the arrangements of operating organizations.
Basis for recommendation: GSR Part 7 paragraph 4.12 states: "The regulatory body is required to establish or adopt regulations and guides to specify the principles, requirements and associated criteria for safety upon which its regulatory judgements, decisions and actions are based. These principles, requirements and associated criteria shall include principles, requirements and associated criteria for emergency preparedness and response of the operating organization."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ● Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 2**?*

Recommendation 2
Recommendation: RPB, as the regulatory body, should require and enforce that operating organizations develop and maintain emergency arrangements for any facility or practice that could necessitate emergency response actions.
Context:
Observation: RPB, as regulator, does not consistently enforce the need for operating organizations to have emergency plans and procedures, including at facilities also operated by GAEC.
Basis for recommendation: GSR Part 7 paragraph 4.13 states: "The regulatory body shall require that arrangements for preparedness and response for a nuclear or radiological emergency be in place for the on-site area for any regulated facility or activity that could necessitate emergency response actions. Appropriate emergency arrangements shall be established by the time the source is brought to the site, and complete emergency arrangements shall be in place before the commencement of operation of the facility or commencement of the activity. The regulatory body shall verify compliance with the required arrangements."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ○ Significant progress
- ● Complete progress

How much progress has been achieved towards **Recommendation 3**?*

Recommendation 3
Recommendation: The government should update the national hazard assessment to include all sources in the country and locations at which there is a significant likelihood of encountering a dangerous source (e.g., border crossing).
Context:
Observation: The national hazard assessment does not include the location of all radioactive sources in the country, and is not updated on a regular basis.

Basis for recommendation: GSR Part 7 paragraph 4.25 states: "The government shall ensure that a review of the hazard assessment is performed periodically with the aims of: (a) ensuring that all facilities and activities, on-site areas, off-site areas and locations where events could occur that would necessitate protective actions and other response actions are identified, and (b) taking into account any changes to the hazards within the State and beyond its borders, any change in assessments of threats for nuclear security purposes, the experience and lessons from research, operation and emergency exercises, and technological developments (see paragraphs 6.30, 6.36 and 6.38). The results of this review shall be used to revise the emergency arrangements as necessary."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ● Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 4**?*

Recommendation 4
Recommendation: GAEC and NADMO should coordinate the development of protection strategies for taking protective actions and other response actions effectively in a nuclear or radiological emergency.
Context:
Observation: There is no protection strategy developed for taking protective actions and other response actions effectively in a nuclear or radiological emergency.
Basis for recommendation: GSR Part 7 paragraph 4.27 states: "The government shall ensure that, on the basis of the hazards identified and the potential consequences of a nuclear or radiological emergency, protection strategies are developed, justified and optimized at the emergency preparedness stage for taking protective actions and other response actions effectively in a nuclear or radiological emergency to achieve the goals of emergency response."

- ○ No progress
- ○ Very little progress
- ● Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 5**?*

Recommendation 5
Recommendation: NADMO should ensure that all organizations, including GAEC (especially RPI), receive training and conduct exercises to be able to use the Incident Command System during the response to a nuclear or radiological emergency.
Context:
Observation: The command and control system designated in the country, the Incident Command System, is not implemented by all response organizations and operating organizations who would respond to a nuclear or radiological emergency.
Basis for recommendation: GSR Part 7 paragraph 5.7 states: "Arrangements shall be made for the establishment and use of a clearly specified and unified command and control system for emergency response under the all-hazards approach as part of the emergency management system."

- ○ No progress
- ● Very little progress
- ○ Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 6**?*

Recommendation 6
Recommendation: GAEC, in coordination with NADMO and the operating organizations, should establish a classification system for nuclear or radiological emergencies.
Context:
Observation: There is no classification system in place to ensure an appropriate response to a nuclear or radiological emergency.
Basis for recommendation: GSR Part 7 paragraph 5.14 states: "The operating organization of a facility or activity in category I, II, III or IV shall make arrangements for promptly classifying, on the basis of the hazard assessment, a nuclear or radiological emergency warranting protective actions and other response actions to protect workers, emergency workers, members of the public and, as relevant, patients and helpers in an emergency in accordance with the protection strategy."

- ○ No progress
- ○ Very little progress
- • Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 7**?*

Recommendation 7
Recommendation: The government should designate a single warning point for emergency notifications, which is able to send and receive information from other states and the IAEA.
Context:
Observation: Ghana does not have a warning point available for international notification, and does not have any users registered for the available international systems.
Basis for recommendation: GSR Part 7 paragraph 5.19 states: "The State shall make known to the IAEA and to other States, directly or through the IAEA, its single warning point responsible for receiving emergency notifications and information from other States and information from the IAEA. This warning point shall be maintained continuously available to receive any notification, request for assistance or request for verification and to initiate promptly a response or verification."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ○ Significant progress
- • Complete progress

How much progress has been achieved towards **Recommendation 8**?*

Recommendation 8
Recommendation: The Ghana Health Service should develop training for medical personnel on the recognition of symptoms of radiation overexposure to allow for the provision of first aid and critical medical treatment.
Context:
Observation: Medical personnel around the country are not trained on how to identify symptoms of radiation sickness.
Basis for recommendation: GSR Part 7 paragraph 5.60 states: "Arrangements shall be made for medical personnel, both general practitioners and emergency staff, to be made aware of the clinical symptoms of radiation exposure and of the appropriate notification procedures and other response actions that are warranted if a nuclear or radiological emergency has occurred or is suspected."

- ○ No progress
- ○ Very little progress

- Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 9?***

Recommendation 9
Recommendation: The Ministry of Health should define arrangements for providing definitive care for patients with radiation injuries and/or contamination.
Context:
Observation: There are no arrangements at the national level to refer potentially contaminated and/or injured persons and accidentally overexposed victims to a specialized facility for medical treatment.
Basis for recommendation: GSR Part 7 paragraph 5.64 states: "Arrangements shall be made to identify people with possible contamination or having possibly been exposed sufficient to result in radiation induced health effects and to provide them with appropriate medical attention including longer term medical follow up. These arrangements shall include: (a) guidelines for effective diagnosis and treatment; (b) designated medical personnel trained in clinical management of radiation injuries; (c) designated institutions for evaluating radiation exposure (external and internal), for providing specialized medical treatment and for longer term medical actions."

- ○ No progress
- ○ Very little progress
- Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Suggestion 4**?*

Suggestion 4
Suggestion: NADMO and GAEC should consider ensuring that the nuclear or radiological emergency and the emergency response are systematically analyzed in order to identify actions to be taken to prevent other emergencies and to improve emergency arrangements.
Context:
Observation: There is no program to analyze the emergency and emergency response.
Basis for suggestion: GSR Part 7 paragraph 5.99 states: "Arrangements shall be made to document, protect and preserve, to the extent practicable, in an emergency response data and information important for an analysis of the nuclear or radiological emergency and the emergency response. Arrangements shall be made to undertake a timely and comprehensive analysis of the nuclear or radiological emergency and the emergency response with the involvement of interested parties. These arrangements shall give due consideration to the need for making contributions to relevant internationally coordinated analysis and for sharing the findings of the analysis with relevant response organizations…."

- ○ No progress
- ○ Very little progress
- Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 10**?*

Recommendation 10
Recommendation: The government should ensure that the overall organization for emergency preparedness and response is clearly specified and staffed with sufficient personnel who are qualified for their intended duty.

Context:
Observation: The NNRERP establishes roles and responsibilities of organization involved in a radiological emergency but these organizations have not considered what the minimum number and the qualification of personnel is needed to fulfill these responsibilities.
Basis for recommendation: GSR Part 7 paragraph 6.10 states: "Appropriate numbers of suitably qualified personnel shall be available at all times (including during 24 hour a day operations) so that appropriate positions can be promptly staffed as necessary following the declaration and notification of a nuclear or radiological emergency. Appropriate numbers of suitably qualified personnel shall be available in the long term to staff the various positions necessary to take mitigatory actions, protective actions and other response actions."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ○ Significant progress
- ● Complete progress

How much progress has been achieved towards **Recommendation 11**?*

Recommendation 11
Recommendation: GAEC should document the emergency response procedures that will be implemented should a nuclear or radiological emergency occur at the Ghana Research Reactor 1 (GHARR-1) or the larger GAEC site.
Context:
Observation: The Ghana Atomic Energy Commission (GAEC), as the operator of the Ghana Research Reactor 1 (GHARR-1), has not established the emergency procedures that should support the existing emergency preparedness and response plan.
Basis for recommendation: GSR Part 7 paragraph 6.20 states: "The operating organization and response organizations shall develop the necessary procedures and analytical tools to be able to perform the functions specified in Section 5 for the goals of emergency response to be achieved and for an emergency response to be effective."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ○ Significant progress
- ● Complete progress

How much progress has been achieved towards **Suggestion 5**?*

Suggestion 5
Suggestion: The government should consider regularly updating the list of available equipment for emergency response.
Context:
Observation: The list of available emergency equipment from facilities and response organizations is not complete and is not updated on a regular basis.
Basis for suggestion: GSR Part 7 paragraph 6.22 states: "Adequate tools, instruments, supplies, equipment, communication systems, facilities and documentation (such as procedures, checklists, manuals, telephone numbers and email addresses) shall be provided for performing the functions specified in Section 5. These items and facilities shall be selected or designed to be operational under the conditions (such as radiological conditions, working conditions and environmental conditions) that could be encountered in the emergency response, and to be compatible with other procedures and equipment for the response (e.g. compatible with the communication frequencies of other response organizations), as appropriate. These support items shall be located or provided in a manner that allows their effective use under the emergency conditions postulated."

- ○ No progress

- ○ Very little progress
- ○ Some progress
- • Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 12**?*

Recommendation 12
Recommendation: GAEC should establish a central alarm station and emergency center with adequate equipment, including redundant power supplies, and which are not in the same building as the research reactor.
Context:
Observation: GAEC does not have a facility emergency centre. The Central Alarm Station (CAS) is not staffed 24/7, mainly because it does not have redundant power supplies and cannot function without offsite power.
Basis for recommendation: GSR Part 7 paragraph 6.24 states: "Emergency response facilities or locations shall be designated to support the emergency response under the full range of postulated hazardous conditions."

- ○ No progress
- ○ Very little progress
- • Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 13**?*

Recommendation 13
Recommendation: NADMO and GAEC should ensure that a training program is developed and implemented for first responders and other response organizations.
Context:
Observation: Training programs for first responders to a radiation emergency are not formalized, and training is not systematically implemented to ensure organizations at all levels are able to perform preparedness and response functions.
Basis for recommendation: GSR Part 7 paragraph 6.28 states: "The operating organization and response organizations shall identify the knowledge, skills and abilities necessary to perform the functions specified in Section 5. The operating organization and response organizations shall make arrangements for the selection of personnel and for training to ensure that the personnel selected have the requisite knowledge, skills and abilities to perform their assigned response functions. The arrangements shall include arrangements for continuing refresher training on an appropriate schedule and arrangements for ensuring that personnel assigned to positions with responsibilities in emergency response undergo the specified training."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- • Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 14**?*

Recommendation 14
Recommendation: The government should ensure that exercise programs are established for all facilities and practices, that all response organizations are included, and that the exercises are systematically evaluated.

Context:
Observation: There have been no drills or exercises conducted by facilities identified as emergency preparedness category III, and there is no national exercise program in place for practices identified as emergency preparedness category IV.
Basis for recommendation: GSR Part 7 paragraph 6.30 states: "Exercise programmes shall be developed and implemented to ensure that all specified functions required to be performed for emergency response, all organizational interfaces for facilities in category I, II or III and the national level programmes for category IV or V are tested at suitable intervals. These programmes shall include the participation in some exercises of, as appropriate and feasible, all the organizations concerned, people who are potentially affected and representatives of news media. The exercises shall be systematically evaluated (see para. 4.10(h)) and some exercises shall be evaluated by the regulatory body. Programmes shall be subject to review and revision in the light of experience gained (see paras 6.36 and 6.38)."

- ○ No progress
- ○ Very little progress
- ● Some progress
- ○ Significant progress
- ○ Complete progress

How much progress has been achieved towards **Recommendation 15**?*

Recommendation 15
Recommendation: The government should ensure that the defined quality management program is implemented and documentation is maintained.
Context:
Observation: The defined quality management program contained in the NNRERP is not implemented or documented.
Basis for recommendation: GSR Part 7 paragraph 6.36 states: "Arrangements shall be made to maintain, review and update emergency plans, procedures and other arrangements and to incorporate lessons from research, operating experience (such as in the response to emergencies) and emergency exercises."

- ○ No progress
- ○ Very little progress
- ○ Some progress
- ● Significant progress
- ○ Complete progress

August 2023 *Kwabenya, Ghana*

Annex 2: Interview with Mr. Lennox Assan of the NRA

Disclaimer: "The comments provided by Mr. Lennox Assan throughout this interview are solely his personal insights which do not represent the official stance of the government of Ghana or any affiliated institution. Mr. Assan has generously shared his expertise based on his individual perspective, and his remarks should not be construed as an authoritative statement on behalf of the NRA."

Follow-up Interview

Nuclear and Radiological Emergency Preparedness in Ghana

2015 – 2023 Progress and Challenges

(August 2023)

The results of self-assessment questionnaire your colleagues and you had filled in indicate that progress has been made towards all suggestions and recommendations provided by the IAEA through the 2015 EPREV Mission. I would like to inquire in more detail about the suggestions and recommendations where you indicated only 'very little' or 'some' progress has been made. In your professional opinion, what are the reasons less progress has been made in these areas than the others. What are the main challenges and obstacles? Please see below an overview of recommendations and suggestions I am referring to:

Suggestion / recommendation	**Progress level**
Suggestion 1: Review and revision of NDMP & NNRERP	Some
Recommendation 4: Development of protection strategies	Some
Recommendation 5: ICS training and exercises	Very little
Recommendation 6: Classification system for emergencies	Some
Recommendation 8: Training for medical personnel	Some
Recommendation 9: Definitive care for contaminated patients	Some
Suggestion 4: Systemic analysis of emergencies	Some
Recommendation 12: Central alarm station and emergency center	Some
Recommendation 14: Comprehensive exercise programs	Some

Answers

SUGGESTION 1: The current National Nuclear and Radiological Emergency Response Plan has not been revised since the Nuclear Regulatory Authority was set up in 2016. The current document is still in its draft process.

RECOMMENDATION 4: Very little collaborative work has been done between National Disaster Management Organization and the Nuclear Regulatory Authority over the past few years. Reasons for this vary – from absence of a well-documented policy of action between the two agencies, as well as frequent change in leadership at both of the agencies.

RECOMMENDATION 5: Not much training and exercises have been conducted by National Disaster Management Organization on the use of the Incident Command System. Most of the trainings conducted are theoretical and lack the practical element.

RECOMMANDATION 6: Classification system currently in use has been sourced from the IAEA 2015 GSR Part 7 – "Preparedness and Response for a Nuclear or Radiological Emergency".

RECOMMENDATION 8: Medical personnel have not gone through any special training by the Ghana Health Service on radiation protection. Any knowledge on radiation protection by an individual health worker is based on their own personal knowledge acquisition.

RECOMMENDATION 9: There is no designated facility at the national level to offer medical treatment to people who have been contaminated or with radiation injuries.

RECOMMENDATION 12: A designated station has been set up; however, it is not well resourced.

RECOMMENDATION 14: There have not been any exercise programs conducted with all stakeholders involved. Reasons cited for this include lack of coordination among stakeholders, limited resources and time constraints.