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NUCLEAR SECURITY CHALLENGES AND DETECTION ARCHITECTURE DEVELOPMENTS IN NORTHEAST AFRICA: A COMPREHENSIVE ANALYSIS

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Abstract

Preventing terrorist organizations from getting and using nuclear weapons is a critical global challenge. Among the issues facing nuclear security in northeast Africa are illicit trafficking, political instability, the lack of regulatory frameworks, and limited technical capabilities. Countries like Egypt, Sudan and Ethiopia, are increasingly aware of these threats and are actively working to develop their nuclear security and detection architectures and address them. Effective nuclear threats mitigation relies on identifying and intercepting illicit nuclear material movements before they can be used for malicious purposes. This paper examines nuclear security challenges and threats and Nuclear Developments in Northeast Africa in focusing on regulatory frameworks, technological advancements, and regional and international cooperation and conventions related to nuclear security. It underscores the importance of a robust detection architecture, highlights the need for continuous improvement in regulatory measures, and calls for stronger international collaboration. Recommendations for future enhancements are also provided.

Keywords: nuclear security, northeast Africa, detection architecture, international cooperation, Convention, regulatory frameworks, illicit trafficking

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Introduction

Today, nuclear security is one of the most important concerns on the global agenda. Countries in Northeast Africa face unique nuclear security challenges that require immediate attention. The purpose of this introduction is to provide an overview of the key challenges that this region faces as well as the significance of addressing them. Northeast Africa faces significant nuclear security challenges that require a comprehensive approach. As countries in the region address threats, it is possible to manage nuclear materials securely by investing in detection architecture development and Improve Nuclear Security. It is imperative to

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collaborate, build capacity, and adhere to international standards to ensure nuclear security.

Nuclear materials are identified and tracked using sensors and monitoring systems in the detection architecture. However, detecting nuclear materials can be challenging due to their ability to be shielded and hidden, making it difficult to identify with standard equipment. Additionally, the presence of naturally occurring radioactive materials can result in false positives, complicating the detection process further. Ensuring the reliability and accuracy of these systems requires constant technological advancements and rigorous testing.

Detection systems can range from fixed installations at ports and borders to mobile units, which can be deployed in response to specific threats. An integrated detection architecture provides real-time monitoring and early warnings of unauthorized nuclear material access by integrating various technologies and sources. Following that, it examines global and regional trends in nuclear security, including best practices and challenges. In this review, I identify specific gaps in the literature that my research aims to fill, establishing the foundation for understanding nuclear security challenges and the need for tailored detection systems. I am planning to examine the current ability of some African countries to detect and respond to nuclear threats, as well as the potential risks associated with inadequate security measures. An analysis of nuclear security challenges and regulatory frameworks in Northeast Africa is presented, focusing on recent technological advancements and international cooperation efforts that explain international agreement and conventions in nuclear security. It emphasizes the need for robust nuclear security regime and detection architectures, stronger regulatory measures, and increased collaboration. In addition, recommendations are provided for future improvements aimed at making regional frameworks more secure.

Table 1: List of abbreviations and acronyms used in this article

Abbreviation	**Explanation**
1	2
CONOPs	Concept of Operations in Nuclear Security
IAEA	International Atomic Energy Agency
NDT	Non-Destructive Testing
ERPA	Ethiopian Radiation Protection Authority
ENRPA	Ethiopian Nuclear and Radiation Protection Authority
ITDB	Incident and Trafficking Data Base

Continued

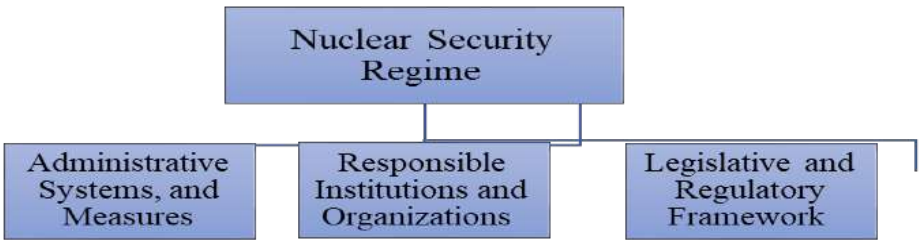
1	2
WINS	World Institute for Nuclear Security
INSEN	International Nuclear Security Education Network
NTI	Nuclear Threat Initiative
INSF	International Nuclear Security Forum
CPPNM	Convention on the Physical Protection of Nuclear Material
RPMs	Radiation Portal Monitors
NPPs	Nuclear Power Plants
RRs	Research Reactors
RDD	Radiological Dispersal Devices
PSI	The Proliferation Security Initiative
GICNT	Global Initiative to Combat Nuclear Terrorism
SNRRA	Nuclear Radiological Regulatory Authority
FNRBA	Forum of Nuclear Regulatory Bodies in Africa
JRC	Joint Research Center

Note: Full reference for the source are available in the reference section

Nuclear Security and Nuclear Security Regime

According to the IAEA, nuclear security focuses on preventing, detecting, and responding to criminal or intentional unauthorized activities related to nuclear material, other radioactive materials, associated facilities, or associated activities. In other words, security means protecting nuclear and other radioactive facilities from threats that are not related to technology or manufacture. Among the intentional security threats, there are terrorist attacks, theft and assault, sabotage, cyber threats, and information security threats that threaten to damage the nuclear facility and release radioactive material. There are three major components of the nuclear security regime. The first are the laws and regulations that govern security on a nation‘s territory. Second, there are international agreements, instruments, and United Nations Resolutions that complement domestic security laws. The third is to cooperate and collaborate with the national competent authority and to follow the recommendations of the IAEA regarding nuclear security (IAEA, 2011).

Hence, to achieve nuclear security goals the government needs to ensure that all stakeholders who have responsibilities within the State's nuclear security regime are competent. Achieving clarity of responsibility in the way recommended by the IAEA is not an easy task. It needs much effort, particularly because the number of potential stakeholders with responsibilities for security is large. In fact, it is much larger than the number of stakeholders who manage nuclear safety on a licensed nuclear site where legal accountability rests exclusively with the licensee. For these reasons, it is particularly important that all stakeholders take initiative-taking steps to understand the limits of their legal accountability. Specifically in nuclear security this should be clear and following are some of the essential nuclear security regimes that countries should develop. To implement these regimes effectively, countries should establish comprehensive legal frameworks that outline clear regulations and procedures for nuclear security. Additionally, they should invest in robust training programs for personnel, ensuring that they are well-equipped to manage potential threats. Regular audits and inspections should also be conducted to identify and address any vulnerabilities in nuclear facilities.



Source: Author base on IAEA (2013).

Figure 1: The Nuclear Security Regime Component

Since 1993, the Ethiopian Nuclear and Radiation Protection Authority (ENRPA), formerly known as the Ethiopian Radiation Protection Authority (ERPA), has served as the nation's regulatory control body for the use of ionizing radiation sources. The Ethiopian parliament approved legal requirements that will upgrade the Ethiopian regulatory body's scope for upcoming activities as ENRPA following the 2017 nuclear program. There are provisions in the new Nuclear and Radiation Protection Proclamation (Proclamation, 2017). The purpose of this proclamation is to ensure the peaceful use of radiation and nuclear technologies to support national socioeconomic and technological development by regulating safety, security, and safeguards; protect individuals, society, and the environment, both current and future (Reporter, 2023). The Ministry of Innovation

and Technology signed an agreement with Russia to build a Research Reactor focusing on agricultural research, education, and health. On July 27, 2023, the Russian Ethiopian roadmap for cooperation on peaceful uses of atomic energy was signed. It also includes provisions for developing nuclear infrastructure and human resource training. The cooperation is expected to foster economic growth and sustainable development in Ethiopia through the peaceful use of atomic energy. It was announced in June 2019 that Ethiopia had ratified a nuclear and science and technology program with the support of the Russian government as well as the International Atomic Energy Agency. In order to develop a successful nuclear program, the country plans and prepares infrastructure that can support the use of nuclear science and technology in all sectors of the economy (Berihie, 2022).

On 11 January 2017, the National Assembly approved the nuclear law and according to the law, an independent regulatory authority that regulates nuclear and radiological activities in Sudan, was established to be known as the Nuclear Radiological Regulatory Authority (SNRRA), The law covers safety, security, and safeguards for nuclear materials, radiation sources, facilities, and all activities involving peaceful uses of nuclear energy and radiation technology in Sudan. According to the law, SNRRA shall establish requirements, by regulations and conditions in an authorization, for the physical protection of nuclear (or other radioactive) material, including categorizing, protecting, and accounting and controlling, authorizing, inspecting, and enforcing non-compliance. A comprehensive regulatory framework in Sudan governs the security of nuclear and other radioactive facilities and activities related to nuclear materials, radioactive materials, and associated facilities and activities. Throughout the lifecycle radioactive sources and nuclear material, a strict regulatory control system, review and assessment process, regulatory framework development, inspection and enforcement processes ensure that they are still under strict regulatory control and in compliance with national regulations as well as licensing conditions.

Nuclear Detection Architecture

A nation's nuclear detection architecture is the framework that integrates the various technical and non-technical elements needed to implement a national strategy for the detection of illicit trafficking of nuclear and other radioactive materials and devices (U.S. Department of Homeland Security, 2009). IAEA defines a national strategy for detecting nuclear and other radioactive materials out of regulatory control as an integrated set of security systems and measures, based on an appropriate legal and regulatory framework. The nuclear security detection architecture is one of the most important components of this system. The program is composed of various activities, technologies, and policies designed to prevent the acquisition and transport of nuclear and other radioactive materials

under unauthorized conditions. Among these components are physical protection systems, advanced radiation detection technologies, intelligence sharing, regulatory frameworks, and specialized training (IAEA, 2013).

An effective nuclear security detection architecture is essential for the implementation of the national detection strategy, since it enhances a state's ability to monitor and control the movement of nuclear and other radioactive materials to protect people, property, society and the environment from harmful outcomes of a nuclear security event (IAEA, 2013). The purpose of this policy is to assign responsibilities for detecting crimes to different agencies and authorities related to systems for detection of criminal or unauthorized acts with nuclear security consequences. Assigning responsibilities ensures that each agency or authority clearly understands their role in maintaining security. It helps prevent overlaps and gaps in security measures, thereby enhancing the overall effectiveness of the system. Additionally, it facilitates accountability, making it easier to identify and address any security breaches swiftly.

Concepts of Operation (CONOPs) in Nuclear Security

The operational component of nuclear or radiological accidents defines how they are prepared for, responded to, and resolved. As part of CONOP, mobile detection instruments are deployed based on intelligence information or information alerts and are relocatable, wearable, handheld, vehicle-based, or other types. These instruments include portable radiation detectors, handheld chemical analyzers, and vehicle-mounted surveillance systems. Wearable sensors can monitor environmental conditions, while drones equipped with advanced imaging technology can cover large areas quickly. Each type serves a specific purpose in ensuring comprehensive and flexible detection capabilities in various scenarios. Deploying vehicle-based detection instruments presents several challenges. These include ensuring that the instruments remain calibrated and accurate despite the vibrations and movements of the vehicle. Additionally, there are logistical issues such as maintaining power supply and ensuring secure data transmission while on the move (Tengblad, Peräjärvi, Toivonen, Tagziria, Kröger, 2019). As part of the concept of operations, the systems and measures should be implemented and supported by communication, law enforcement, intelligence agencies, compliance systems, and human resources (e.g. enforcement officials, experts, local and national response teams, other authorities) to ensure their effectiveness (IAEA, 2013).

Customs officers ensure that goods and people entering a country are secure and comply with the law. A primary and secondary inspection is among the duties of customs officers on the front lines to prevent illegal activities such as smuggling and trafficking. To prevent such activities, they check documentation,

assess declarations, and enforce regulations. As part of a primary inspection, frontline officers monitor traffic flow at Checkpoint (like border crossings) using radiation portal monitors (RPM).

Table 2: Role and Responsibility in Concepts of Operation (CONOPs) in nuclear security

Tasks	Authorities Involved	Description of Roles
1. Detection	Front Line Officers, Sensors	Initial detection of suspicious materials or radiation sources.
2. Identification	Technical Specialists, Labs	Determine the nature and type of the detected material.
3. Localization	Command & Control, Field Units	Pinpoint the exact location of the source.
4. Material Characterization	Labs, Technical Units	Analyze and classify the material properties in detail.
6. Threat and Risk assessment	Command & Control, Experts	Comprehensive evaluation of potential threats and risks.
7. Response or Interdiction	Law Enforcement, Response Teams	Deploy interdiction or response measures to neutralize threat.
6. Threat and Risk Assessment	Command & Control, Experts	Comprehensive evaluation of potential threats and risks.

Source: Ihantola et al. (2019).

Overview of Nuclear Developments in Northeast Africa

In North Africa, radioactive materials such as technetium-99m, iodine-131, and cobalt-60 are commonly used. The materials are used in diagnostic and therapeutic procedures such as nuclear imaging and radiotherapy. A radiological source is used in industry for non-destructive testing (NDT) and radiography. Currently, eleven research reactors are located in eight countries across the continent, but governments throughout the continent are increasingly interested in developing nuclear reactor facilities (IAEA, 2020), where 16 of the 29 new reactors are being built in developing countries. Moreover, 17 African states have shown interest so far in embarking on nuclear projects: some have active nuclear research program in place, while others are considering nuclear construction. For example, Egypt is currently constructing four nuclear reactors, while South Africa is constructing a fifth (IAEA, 2020). Despite the promising advances, nuclear reactor construction faces several challenges, including high initial investment costs, regulatory hurdles, and public opposition due to safety concerns. It is

important to examine what nuclear material exists in various African countries in order to better understand nuclear security in Africa increasingly; nuclear power is becoming a topic of discussion in Northeast Africa. There has been a growing interest in developing civil nuclear sectors in some countries despite military considerations dominating the nuclear landscape. No nuclear power plants (NPPs) are operational in Northeast Africa now. In spite of this, some countries are considering nuclear power for the generation of electricity – Egypt is one of these countries and has made significant progress in this regard in the past few years with the El Dabaa nuclear power plant that has significant desalination capacity has four units with VVER-1200 reactors. These plants are expected to come into operation starting in 2026 (Rosatom, 2024). Sudan and Ethiopia are also exploring the potential of nuclear energy to meet their growing electricity demands, Sudan has shown interest in developing nuclear power and has engaged with the IAEA to assess its readiness (IAEA, 2018). Furthermore, these countries have been committed to investing in nuclear energy, with Sudan already investing in feasibility studies in the scone milestone, and Ethiopia exploring the possibility of constructing a nuclear power plant. Both nations have shown interest in diversifying their energy sources and reducing reliance on fossil fuels. Russia and Ethiopia signed a bilateral agreement on atomic energy cooperation. „The roadmap identifies the specific steps that the parties will take in 2023 – 2025 in order to explore the feasibility of building a nuclear power plant of any size or a nuclear science and technology center in Ethiopia.

Currently, there are ten RRs operating across Africa. Power ranges from 30 kW to 22 MW for these reactors RRs in Africa are a vital component to the development of nuclear science and technology in society and are crucial to the advancement of nuclear energy. Scientists and the public have benefited greatly from the development of these reactors, leading to significant scientific progress in a variety of fields. Research reactors (RRs) have also played a pivotal role in educational development by providing direct training opportunities for students and researchers. These reactors serve as practical laboratories where future nuclear scientists and engineers can gain valuable experience. They are essential in carrying out studies that support nuclear power plants during their entire lifetimes, including training for nuclear power plant operators. States without RRs such as Sudan and Ethiopia are also interested in cultivating a nuclear infrastructure centered on their ongoing RR projects as the first step to commercial nuclear power (IAEA, 2011).

Table 3: Types of Research Reactors in Africa

Country	Facility Name	Type	(kW)
Egypt	ETRR-1	Tank WWR	2000
Egypt	ETRR-2	Pool	22 000
Libya,	IRT-1	Pool IRT	10 000
Algeria	Nur	Pool	1000
Algeria	Es-Salam	Heavy water	15 000
Democratic Rep. of the Congo *	TRICO II	TRIGA Mark II	1000
Ghana	GHARR-1	MNSR	30
Morocco	MA-R1 TRIGA	Mark II	2000
South Africa	SAFARI-1	Tank in pool	20 000
Nigeria	NIRR-1	MNSR	30

*At present on extended shutdown status.

Sources: IAEA (2020).

Nuclear Security Threat in Northeast Africa

It is important to note that the presence of radioactive material in the region poses a great deal of risk, including the potential for accidental exposure or contamination of the environment. If these materials are not properly secured, they could fall into the hands of malicious actors, leading to the creation of radiological dispersal devices (RDD) or „dirty bombs". The impact of such an incident could be devastating for health, the environment, and the economy, so robust security measures are urgently needed. Several low-profile nuclear incidents have occurred in Africa over the past decade. In December 2013, the Rossing Uranium Mine in Namibia experienced a structural failure of a leach tank, resulting in a spill, and in 2014 and 2015, the Koeberg Nuclear Power Station released radioactive waste into the environment (Turianskyi, 2022).

Apart from concerns regarding the impact of nuclear materials on Africa's people and environment, critics also fear that they may fall into the wrong hands because of coups or terrorist attacks. During the past decade, coups in Africa have been much less prevalent than they used to be (there were over 200 coups and attempted coups in Africa between independence and 2012, and over 90% of African states have experienced one). As recent events at the Zaporizhzhia nuclear power plant in Ukraine show, unconstitutional changes of government, conflict, or war may cause instability and threaten nuclear facilities (Turianskyi, 2022).

African countries are particularly concerned about globalization of terror as their stability is deteriorating. Globalization enables local terrorist groups to access international networks and resources, making them more potent and dangerous. It allows them to recruit members from a global pool, secure funding from abroad, and spread their ideologies more widely. Consequently, this international support can exacerbate the instability in African countries, making it harder to maintain security and order. To effectively combat terrorism, African countries need to enhance regional cooperation and intelligence sharing. Strengthening border security and investing in counter-terrorism training for local forces are also crucial steps. Additionally, addressing socio-economic issues that contribute to radicalization can help reduce the appeal of extremist ideologies. It has become more common for terrorists to spread propaganda in recent years. There have been numerous attacks in the Middle East, the beheading of Steven Sotloff, numerous attacks on the embassies in Kenya and Tanzania, 9/11 in the US, 7/7 in London, and Madrid train bombings. These are just a few examples of why civilians are targeted rather than governments. It has become more common for terrorists to attack random targets instead of defined targets, which allows them to kill and maim more people (Larkin, 2016). For instance, the attacks in Paris in 2015 were directed at random civilians, killing 130 and injuring hundreds more. In response to these evolving tactics, counter-terrorism strategies have also been adapted. Governments and security agencies have increased intelligence sharing and collaboration to preempt and disrupt potential threats. Additionally, there has been a significant focus on strengthening cybersecurity measures to combat online radicalization and propaganda (Larkin, 2016). Trafficking in nuclear and other radioactive material became recognized as a potential threat to international security and the non-proliferation of nuclear weapons in the early 1990s. According to IAEA Incident and Trafficking Database (ITDB), the number of incidents, involving unauthorized activities and events involving nuclear and other radioactive material continued to follow historical trends in 2023. 31 States in 2023, an increase of 22 incidents from 2022, reported 168 incidents to the ITDB. There have been 4243 confirmed incidents reported by participating states since 1993 (ITDB, 2024). Information and resources need to be shared as quickly as possible between intelligence organizations around the world to interdict nuclear materials before they reach their intended destinations. Information will need to be freely shared between agencies involved in counterterrorism intelligence, smuggling operations, and interdiction operations. Under UNSCR 1540, an international coordinating body would facilitate closer collaboration among law enforcement and intelligence organizations and manage international nuclear detection activities (Goodby, Coffey, and Loeb, 2007).

A rise in regional instability has resulted in the loss of significant military arsenals; the instability in Sudan has significant regional implications, potentially destabilizing neighboring countries and exacerbating existing tensions. It risks spilling over into South Sudan, where fragile peace efforts could be undermined, and it may influence Ethiopia, which is already grappling with its own internal conflicts. Additionally, the conflict could disrupt regional trade routes and humanitarian aid efforts, affecting the broader Horn of Africa's stability and economic development (Rock, 2023). Three regimes have changed in Ethiopia in the last fifty years, and several wars have been fought. At the same time, Sudan has suffered multiple coup attempts, and Somalia, regarded as the archetype of a „failed state", has endured a long war against al-Shabaab. Political instabilities and conflicts pose significant challenges to nuclear security in the region. Lack of stable governance can lead to inadequate control over nuclear materials, increasing the risk of them falling into the wrong hands. Furthermore, regional instability can also make it difficult to implement effective security measures and international cooperation. The proliferation of nuclear materials in such a volatile environment raises the danger of these resources being used for illicit purposes (Rock, 2023). Terrorist groups, like al-Shabaab, may attempt to exploit these vulnerabilities to acquire nuclear materials. The conflict has affected and involved neighboring countries, which have provided refuge to thousands of displaced people. Others have been accused of providing arms to the warring factions, while some have tried to break up peace talks. There is an urgent need to coordinate international response to regional instability, which has strained diplomatic relations. Several other countries border the Sudan, all of which are volatile countries. The volatile geopolitical landscape has a significant impact on cross-border trade and movement. Because of frequent conflicts and instability, transportation routes can be disrupted, making it difficult for goods and people to move smoothly between Sudan and its neighbors. Consequently, this leads to increased smuggling and illegal transfer of nuclear materials. Such activities pose significant security threats, including the potential for nuclear proliferation. Additionally, they create an environment conducive to terrorism and organized crime, further destabilizing the region.

International Nuclear Security Regime

Many efforts have been made to combat the threat of nuclear terrorism. In this regard, the nuclear security regime is comprised of international rules and laws derived from UN Security Council resolutions, treaties, and conventions. These include UN Security Council Resolutions 1373 and 1540, CPPNM and its amendments, the Nuclear Terrorism Convention. Several groups are also involved, including the Proliferation Security Initiative and the Global Initiative

against Nuclear Terrorism. Additionally, there are the Nuclear Security Summits. Furthermore, there are nuclear security norms and networks, such as the World Institute for Nuclear Security (WINS), the International Nuclear Security Education Network (INSEN), and the Nuclear Threat Initiative (NTI).

The UN Security Council adopted Resolution 1373.

The UN Security Council adopted Resolution 1373 (2001) on September 28, which called for states to prevent and suppress the financing of terrorist acts, refrain from assisting terrorism, enhance cooperation against terrorism, and become parties to international conventions and protocols. The Resolution imposed binding legal obligations on all Member States to adopt proper legislative measures to counter the flow of resources and arms to terrorists and to deny them safe havens. Additionally, it established a global tone for counterterrorism cooperation in the future. With a global scope, the resolution addressed the threat to international peace and security posed by terrorism in all its forms and manifestations, regardless of geography and regardless of the perpetrators' alleged motives. In the resolution, it was stated that international terrorism requires resolute, sustained, and multilateral action (United Nation, 2001).

UN Security Council Resolution 1540

UN Security Council Resolution 1540 (2004) requires member states to act against non-state actors attempting to develop, possess or use nuclear, chemical or biological weapons and their means of delivery. It also establishes a committee to monitor compliance and obliges member states to promote multilateral treaties related to WMD proliferation. Resolution 1540 also requires States to take and enforce effective measures to establish domestic controls to prevent the proliferation of nuclear, chemical or biological weapons and their means of delivery, including by establishing appropriate controls over related materials. International cooperation is essential in ensuring that these measures are uniformly implemented and effective (United Nations Security Council, 2004a). By sharing information, best practices, and technologies, States can collectively strengthen their defenses against the proliferation of such weapons. Additionally, collaborative efforts can help to identify and mitigate potential threats more swiftly. However, implementation has been slow due to capacity and political unwillingness (United Nations Security Council, 2004b).

Convention on the Physical Protection of Nuclear Material (CPPNM) and its Amendment

As the only internationally legally binding undertakings in the field of physical protection of nuclear material and facilities for peaceful purposes, CPPNM entered into force in 1987 and was amended in May 2016, marking a crucial turning point in the development of international legal frameworks for nuclear security. CPPNM and its 2005 amendment are the most important international legal instruments around nuclear security adopted under IAEA auspices (IAEA, 2021).

According to the CPPNM, Parties are legally obligated to protect nuclear material used for peaceful purposes during international transport, to criminalize certain nuclear material-related offences, and to cooperate internationally, for example, in case of theft, robbery, or other unlawful seizure of nuclear material. Because of the treaty's amendment in 2005, which entered into force in 2016, the convention has been strengthened by protecting the peaceful domestic use of nuclear material as well as preventing sabotage of nuclear plants. These peaceful uses include generating electricity through nuclear power plants, medical applications such as cancer treatment with radiation therapy, and agricultural uses like food irradiation to eliminate pests and increase shelf life. Additionally, nuclear materials are used in scientific research and industrial applications, such as non-destructive testing. The IAEA also provides legally non-binding recommendations, such as The Physical Protection of Nuclear Material and Nuclear Facilities and the Code of Conduct on the Safety and Security of Radioactive Sources, to guide states towards physical security for nuclear materials and radioactive sources and key documents include the Nuclear Security Series (IAEA, 2021).

International Convention for the Suppression of Acts of Nuclear Terrorism

In 2005, the UN General Assembly adopted the International Convention for the Suppression of Acts of Nuclear Terrorism (the Nuclear Terrorism Convention), which criminalizes the possession or use of radioactive material with an intent to cause damage, damages facilities with the same intent, or tries to do so. It also promotes cooperation among states and the IAEA to prevent such acts. The Convention requires the Parties to cooperate in preventing nuclear terrorism by exchanging correct and verified information for the detection, suppression, and investigation of these crimes. Parties must establish their jurisdiction over offences committed on their territory, or aboard vessels or aircraft registered in their territory, or when the alleged offender is a national of that state (United Nations, 2005). The International Maritime Organization adopted the SUA

Convention in 1988, which was revised in 2005 to include offenses related to radioactive materials, biologic, chemical, and nuclear weapons. This protocol promotes the nonproliferation efforts by preventing illicit shipments and malicious acts, but not the peaceful use of nuclear energy through exports and imports. The Proliferation Security Initiative (PSI) and the Global Initiative to Combat Nuclear Terrorism (GICNT) are voluntary partnerships that aim to prevent WMD proliferation and nuclear terrorism, respectively. The PSI has 105 participant states, while the GICNT has 86 member states and five international organizations as observers. Both initiatives are legally sound and provide a platform for states to coordinate their activities for counter-proliferation. WINS, INSEN, NTI, and INSF are international initiatives working to prevent nuclear terrorism but lack comprehensive standards and mechanisms to monitor compliance. Awareness of the threat of nuclear terrorism is essential for an effective nuclear security regime.

International Agreement and Conventions Related Nuclear Security for Northeast African

The Ethiopian, Egyptian and Sudanese governments are committed to ensuring the safe and secure handling of nuclear materials. As a result of these agreements and conventions, nuclear security will be enhanced, nuclear terrorism will be prevented, and peaceful nuclear activities will be promoted. The implementation of these agreements will contribute to global efforts to maintain nuclear security and to prevent potential negative consequences associated with nuclear incidents. Various Northeast African countries have established national regulatory bodies and frameworks to oversee nuclear security in 2010, the Law Regulating Nuclear and Radiological Activities (law No. 7) was promulgated. As part of this law, the Arab Republic of Egypt will have a legal framework to regulate nuclear and radioactive activities in a way that ensures that all human beings, their property, and the environment are safe and protected from radioactive hazards. An independent Nuclear and Radiological Regulatory Authority (ENRRA) was established. Regulatory and control functions for nuclear and radiological activities are performed by ENSRA in accordance with its authorities. ENSRA handles ensuring the safe operation of nuclear facilities, protecting public health and the environment from radiological hazards, and enforcing compliance with national and international safety standards. Additionally, it conducts regular inspections and assessments of nuclear sites and provides guidance and training to industry personnel (Amer, 2013).

Table 4: Agreement and conventions related nuclear security to Sudan

Agreements	Date	Status
IAEA Membership	17 July 1958	
Amendment to the Convention on the Physical Protection of Nuclear Material		Non-Party
Convention on the Physical Protection of Nuclear Material	2000-06-17	In Force
Convention on Early Notification of a Nuclear Accident	1986-09-26	Signature:
Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency	1986-09-26	Signature:
African Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA)	2022-08-11	In Force
International Convention for the Suppression of Acts of Nuclear Terrorism		

Source: IAEA (2024).

Table 5: Agreement and conventions related nuclear security to Ethiopia

Agreements	Date	Status
IAEA Membership	1957	
Amendment to the Convention on the Physical Protection of Nuclear Material		Non-Party
Convention on the Physical Protection of Nuclear Material		Non-Party
Convention on Early Notification of a Nuclear Accident		Non-Party
Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency		Non-Party
African Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA)	2024-03-25	acceptance
Application of Safeguards in connection with the Treaty on the Nonproliferation of nuclear weapons (with Protocol):	1977-12-02	Signature
Protocol Additional to the Agreement between the Federal Democratic Republic of Ethiopia and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of nuclear weapons	2019-09-18	Signature
International Convention for the Suppression of Acts of Nuclear Terrorism.		

Source: IAEA (2024).

Table 6: Agreement and conventions related nuclear security to Egypt

Agreements	Date	Status
IAEA Membership	4 September 1957	
Amendment to the Convention on the Physical Protection of Nuclear Material		Non-Party
Convention on the Physical Protection of Nuclear Material		Non-Party
Convention on Early Notification of a Nuclear Accident	1988-07-06	ratification:
Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency	1988-10-17	ratification:
African Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (AFRA)	2023-07-26	acceptance:
Application of Safeguards in connection with the Treaty on the Nonproliferation of nuclear weapons	1982-06-30	In Force
International Convention for the Suppression of Acts of Nuclear Terrorism	20 Sep 2005	Signature

Source: IAEA (2024).

Regional Frameworks

African Union (AU). The AU has developed policies and frameworks to address nuclear security, including the African Nuclear-Weapon-Free Zone Treaty (Treaty of Pelindaba). The Treaty of Pelindaba, which came into force on 15 July 2009. It is significant because it establishes Africa as a nuclear-weapon-free zone, prohibiting the development, possession, and testing of nuclear weapons within the continent. This treaty promotes regional peace and security by preventing the proliferation of nuclear weapons and encouraging the peaceful use of nuclear energy. Additionally, it strengthens global non-proliferation efforts and contributes to the overall goal of a nuclear-free world (FNRBA, 2009). Parties agree to establish the African Commission on Nuclear Energy (AFCONE) with headquarters in Pretoria, South Africa, to ensure compliance with the obligations under the Treaty. In addition to reporting, exchanging information, and reviewing peaceful nuclear activities, it encourages regional and subregional cooperation, as well as international cooperation. Cooperation with the AU, the IAEA, and other nuclear weapons-free zones has been established, and agreements have been signed with AFRA and FNRBA.

To ensure nuclear governance compliance and oversight at national and continental levels, AFCONE should be strengthened, including allocating additional human resources to develop and maintain its website. The Pelindaba Treaty should be signed and ratified by the 55 members of the African Union without delay, and Protocols I, II and III should be signed and ratified without reservations and without further delay by the P5 and Spain of the UN Security Council. To ensure cooperation and optimize resources, AFCONE and IAEA should strengthen their cooperation beyond the existing Practical Arrangements. It is recommended that AFCONE considers a Pelindaba Treaty conference. The Forum of Nuclear Regulatory Bodies in Africa (FNRBA), which was established in 2009, aims to enhance nuclear safety and security across Africa. Currently, it consists of 34 members, and it focuses on five major priorities in six main areas. Among its many functions, it organizes training workshops, publishes technical reports, and helps knowledge-exchange between member states (FNRBA, 2009). The five major priorities include regulatory framework development, safety and security culture promotion, emergency preparedness and response, radiation protection, and waste management. By addressing these key areas, FNRBA ensures a comprehensive approach to nuclear safety. It also fosters collaboration to continuously improve standards and practices across the continent.

The FNRBA faces several challenges, including limited finances and insufficient human resources. To improve collaboration among member states, the FNRBA can create a centralized digital platform where resources and best practices can be shared. The coordination of specific projects could also be enhanced by organizing regular virtual meetings and creating joint task forces. The overall network can also be strengthened by encouraging member states to contribute more resources and expertise (FNRBA, 2009).

To enhance regional and international cooperation, as well as the nuclear and radiation safety and security system at the national level, the SNRRA and ENRPA have joined the Arab Network for Nuclear Regulators (ANNuR). The ANNuR contributes to the development of a technical and financial framework in order to build national/regional capabilities in the safety and security fields by hosting, sponsoring, and providing experts within regional activities. Additionally, the SNRRA and ENRPA actively contribute to the ANNuR's mission of promoting nuclear safety and security through international collaboration.

***European Union (EU)**:*

The member states of the EU have legislation and regulations to implement the nuclear security commitments outlined in the relevant treaties and agreements they sign on behalf of their sovereign governments. The 2005 International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT) States are required

to take all practicable measures, including, if necessary, adapting their laws, to prevent and counter preparations for terrorist offences, including prohibitions against terrorism financing. Regulations agreed at EU level and binding across all member states implement some restrictive measures in counterterrorism within the EU. Additionally, a Europe-wide network of specialized units within national law enforcement agencies that focus on CBRN-related crimes is being evaluated (Anthony, 2013). To combat terrorism, EU legislation has been developed previously to combat money laundering. As an example, Regulation (EC) 2580/2001 provides the relevant national agencies with legal powers to freeze the funds of suspected terrorists, and Regulation (EC) 881/2002 implements decisions of the UN Security Council imposing restrictive measures on terrorist groups, including al-Qaeda. The Commission has proposed updating the common rules governing anti-money laundering and counterterrorism in 2013 with a set of legislative proposals. The European Union facilitates cooperation between the national financial intelligence units of its member states (which play a key role in implementing restrictive measures against terrorism). (anthony, 2013) The EU has implemented a comprehensive nuclear security detection architecture, integrated advanced technologies and coordinated efforts among member states. A five-year project entitled the European Reference Network for Critical Infrastructure Protection (ERNCIP). It focused on the following areas. The use of digital electronics to obtain time-stamped list-mode data has significant advantages over conventional spectrum data acquisition. Additionally, some new gamma and neutron detectors require list-mode data for source localization and signal-to-noise optimization. Multiple detectors can also be time-synchronized with a list-mode approach, enabling simultaneous singles and coincidence spectrometry, such as UV-gated gamma spectrometry. Many measurement and sampling scenarios are too risky for humans, so unmanned vehicles can be used instead. There are many ways to do this, including measuring or sampling at reactors, accident sites, and dirty bombs before and after explosions, as well as searching for sources that are not regulated. When data moves instead of people and samples are used, field teams can respond quickly and accurately. It is essential that agreed formats and protocols are available for efficient reach back. Over the past few years, modern technologies have emerged around radiological detection. A number of new neutron and gamma radiation sensors have been developed, and their capabilities have been enhanced. (Tengblad, Peräjärvi, Toivonen, Tagziria, Kröger, 2019).

The European Radiological Data Exchange Platform In. 1995, EURDEP was established to exchange radiological monitoring data between participating countries almost in real time. The platform utilizes advanced data transmission technology to ensure seamless and rapid communication. It employs standardized protocols and robust security measures to maintain the accuracy and confidentiality

of the information shared. Additionally, EURDEP integrates various national monitoring networks into a cohesive system for efficient data aggregation and analysis (European Commission, 2013). In normal conditions, data should be provided at least once a day, and in an emergency, it should be delivered at least once an hour. Two thematic institutes in the EU Joint Research Center (JRC) deal with safeguards and nuclear security. First, the Institute for the Protection and Security of the Citizen (IPSC) has expertise in containment, surveillance, process monitoring, near-real-time accountancy (which provides updates of nuclear material balances), and nuclear material accountancy and control (including technologies such as mass and volume measurements). Since the 1990s, the JRC has used these and other institutes to develop a nuclear security strategy known as the Model Action Plan (working with the IAEA and Interpol), which aims to create a coherent and integrated approach to address illicit trafficking of nuclear weapons and materials through prevention, detection, and response. In addition to the programs outlined above, the European Union has other programs to address the capacity challenges associated with implementing the nuclear security obligations set out in Resolution 1540. As part of its initiative-taking agenda, the European Union has supported the 1540 Committee and UN Office of Disarmament Affairs in their outreach activities in regions where 1540 implementation is low. At times, this outreach has been well targeted and effective; at others, it has been less so, undermined by a lack of sensitivity to the particular needs, concerns, and capabilities of developing states (Boureston, and Ogilvie-White, 2010).

Recommendations to Strengthen the Nuclear Security in Egypt, Sudan, and Ethiopia

Following are recommendations for addressing the unique nuclear security challenges in Northeast Africa, particularly Egypt, Sudan, and Ethiopia. *Improve Legal and Regulatory Frameworks:* Governments should focus on aligning national laws with international nuclear security standards. Enacting clear legislation with enforcement mechanisms will deter nuclear trafficking. **Egypt**, a relatively stable and technologically advanced country in Northeast Africa, has the potential to lead regional nuclear security efforts. However, as a non-party to both the Convention on the Physical Protection of Nuclear Material (CPPNM) and its Amendment, Egypt currently lacks a formal commitment to these international nuclear security standards. Ethiopia's non-participation in both the Convention on Early Notification of a Nuclear Accident (1986) and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1987) presents challenges for the country's nuclear security and

emergency response capabilities. In addition to **Sudan** non-participation in the International Convention for the Suppression of Acts of Nuclear Terrorism (2005) and Amendment to the Convention on Physical Protection of Nuclear Material (CPPNM) (2005), international agreements are vital for strengthening nuclear security globally, especially in preventing nuclear terrorism and making nuclear materials physically safe.

Improving Border Security and Detection Infrastructure, the countries should enhance their border security by increasing the installation of radiation detection systems at key entry points, including border crossings, airports, and seaports, particularly along the Mediterranean and Red Sea coasts. These areas are vital for preventing illicit nuclear material trafficking.

Lead Regional Training and Capacity-Building Initiatives. Leveraging its resources, Egypt could take the lead in organizing regional training programs on nuclear detection. Collaborating with the International Atomic Energy Agency (IAEA) and institutions like the Egyptian Atomic Energy Authority, Egypt could host workshops and facilitate information sharing with Sudan, Ethiopia, and other neighboring countries.

Develop Advanced Nuclear Forensics Capabilities. Establishing nuclear forensics capabilities would be essential for identifying and countering nuclear trafficking networks. This could involve creating specialized laboratories and expertise to analyze seized materials, enabling Egypt and its neighbors to more effectively track the origins of illicit nuclear material.

Conduct Joint Nuclear Security Exercises. The countries should organize joint nuclear security exercises with regional partners to enhance preparedness and foster mutual trust. These exercises will improve the coordination of response protocols for potential nuclear security incidents and strengthen cross-border cooperation.

Invest in Training for a Skilled Workforce. Developing a proficient local workforce in nuclear security protocols is crucial. Egypt should invest in comprehensive training programs aimed at building expertise in nuclear security, forensics, and radiation detection. Strengthening partnerships with international organizations will help address existing expertise gaps, providing more direct training for personnel across the region.

Conclusions

Northeast Africa has several opportunities to enhance its Nuclear Security detection architectures, despite the challenges. International support, regional cooperation, and adoption of advanced technologies can help these countries improve their nuclear security systems. International assistance plays a key role in strengthening local capabilities by providing financial resources, technical exper-

tise, and training. By collaborating with global nuclear security organizations, it facilitates knowledge exchange and best practices. Furthermore, international assistance can be useful in establishing regulatory frameworks and ensuring compliance with international standards. Together, these countries can enhance Northeast Africa's nuclear security landscape and contribute meaningfully to global nuclear nonproliferation efforts. Finally, enhancing intelligence sharing among neighboring countries and international partners can improve the detection and prevention of illicit nuclear activities.

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